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# JOURNAL OF PALEONTOLOGY

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The Paleontological Society
*An Affiliate of the Geological Society of America*
*and*
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*A Division of the American Association of Petroleum Geologists*

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# JOURNAL of PALEONTOLOGY

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JOURNAL OF PALEONTOLOGY, VOL. 9, NO. 3, PP. 183–217, PL. 21, APRIL, 1935

# GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF REEF-CORALS IN JAPAN[1]

HISAKATSU YABE AND TOSHIO SUGIYAMA
Tôhoku Imperial University, Sendai, Japan

## ABSTRACT

In the pre-Pleistocene formations of the Japanese Islands corals occur at several horizons. The Chichibu system, Lower Carboniferous to Permian, contains them in abundance as far north as lat. 40°. Corals are negligible in the Triassic and Lower and Middle Jurassic deposits. The Upper Jurassic Torinosu limestone contains corals as far north as lat. 37°. The Lower Cretaceous rocks contain reef organisms as far north as lat. 43°. The Upper Cretaceous deposits have few corals. So also the Tertiary for the greater part, though some coralline limestones are known. The Riukiu limestone (probably late Pliocene) of the southern islands contains extensive coral reefs as far north as lat. 28°. From these 68 species, in 38 genera, are listed. The fauna is not greatly different from the living fauna of the same region. Calcareous algae were important in all of the pre-Pleistocene coral-bearing formations. In the Pleistocene as a whole the Japanese Islands were at a lower level and the climate was cooler than at present. Few corals are found. In post-Pleistocene time coralline deposits are abundant both as raised reefs and as living reefs. From raised reefs of Taiwan (Formosa) and the Riukiu Islands 31 genera are listed. A raised reef near Tateyama (Awa, Honshû), representing the last submergence, has yielded a large fauna, including 46 species, in 27 genera. In the present seas reef corals are growing on the southern margins of Honshû, Shikoku, and Kiûshû; on the Riukiu Islands, on the Ogasawara group, and on Taiwan. These sites are interpreted as rocky bottoms submerged in Recent time. The northernmost reef-coral growth is at lat. 35°. Conditions affecting corals on these reefs are discussed, and comparisons are made with other regions. It is inferred that the present fauna is derived from more southerly regions by migration in Recent time. Three subfaunas of Recent corals are recognized and their relationships shown. Contrary to expectation, the northern subfauna, as now known, does not show fewer species than the southern subfaunas, but this is believed to be due to accidental circumstances. A list of the Recent corals in 22 geographic areas is presented as the basis for part of the discussion.

## I. COLONIAL OR REEF-BUILDING CORALS FOUND IN THE PRE-PLEISTOCENE FORMATIONS OF THE JAPANESE ISLANDS

Stromatoporoids are reef-building organisms of the Ordovician, Gotlandian and Devonian periods. Remains of these organisms are found in the Ordovician limestones of North China, Manchuria and northern Korea,[2] where, however, we have not any case recorded of their occurrence as actual reefs.[3] In the Japanese Islands, where no fossiliferous older Palaeozoic deposits exist, the older coralline rocks are those of the Chichibu system, the Japanese Palae-

[1] Manuscript received April 1, 1934.

[2] Yabe, H., and Sugiyama, T., On some Ordovician stromatoporoids from South Manchuria, North China and Chôsen (Corea), with notes on two European forms: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 14, no. 1, 1930; Notes on two stromatoporoids from Chôsen (Corea): *Jap. Jour. Geol. Geogr.*, vol. 8, nos. 1–2, 1930.

[3] The term "reefs" is here used in the broad sense long in use among geologists, without defining that structure, so much disputed in the current discussions of "coral reefs and coral islands."

zoic, which is Lower Carboniferous to Upper Permian in geological age, at least in its fossiliferous parts. Genera of coralline organisms prevailing in our Lower Carboniferous limestones are *Lithostrotion*, *Lonsdaleia*, *Diphyphyllum*, and *Chaetetes*. The Chichibu system in the middle part of the Kitakami Mountainland[4] in northeast Japan consists of clay-slates with several interbedded limestone zones, some of which contain in profusion Lower Carboniferous corals, such as *Lonsdaleia japonica* Yabe and Hayasaka, *Lithostrotion pseudomartini* Yabe and Hayaska, *Lithostrotion densitabulata* Yabe and Hayasaka, *L. peculiare* Yabe and Hayasaka, *Diphyphyllum flexuosum* Yabe and Hayasaka, *D. equiseptatum* Yabe and Hayasaka, and *Syringopora reticulata* Goldfuss. A Lower Carboniferous coralline limestone is found also in the southern part of the Abukuma Mountainland, near Hitachi-machi, where it is interbedded in a series of metamorphosed rocks.

In the Inner Zone of southwest Japan there are two well known localities of Lower Carboniferous corals: (1) Ômi in the province of Echigo and (2) Akiyoshi and Ofuku Plateaux in the province of Nagato. The steeply inclined Ômi limestone, of considerable thickness, more than 2000 m. by estimation, and destitute of distinct stratification, has a coral zone of Lower Carboniferous age in its apparently upper, but stratigraphically lower part. Corals collected by Hayasaka from this zone are *Lonsdaleia floriformis crassiconus* M'Coy, *Waagenophyllum omiense* (Yabe and Hayasaka), *Echigophyllum giganteum* Hayasaka, *Axonophyllum gracilis* Hayasaka and *Chaetetes* sp.[5] Likewise the overturned younger Palaeozoic complex of the Akiyoshi district comprises a series of massive limestones, more than 500 m. thick, in its apparently upper, but stratigraphically lower, half; and a series of shales and hornstones, with interbedded limestone lenses, in all 300 to 400 m. thick, in the other half. A Lower Carboniferous limestone zone exposed along the southern border of the Akiyoshi plateau contains many corals, among which the late Y. Ozawa discriminated *Lonsdaleia floriformis crassiconus* M'Coy, *L. enormis* Ozawa, *Nagatophyllum satoi* Ozawa, *Polycoelia japonica* Ozawa and *Chaetetes* sp.[6] It is worthy of note that the Lower Carboniferous coral faunas of Japan and western Europe have several closely allied elements in common.

Upper Carboniferous limestones of southern Manchuria and northern Korea have a peculiar coral fauna, of which the principal elements are colonial *Arachnastraea* and *Cystophora*, and the solitary *Caninia*. This

[4] Endô, R., Palaeozoic stratigraphy of southern Kitakami Mountainland (in Japanese): *Geol. Soc. Tokyo, Jour.*, vol. 31, 1925. Yabe, H., and Hayasaka, I., Palaeozoic corals from Japan, Korea and China: *Idem*, vol. 22, 23, 1915–16.

[5] Hayasaka, I., On the fauna of the Anthracolithic limestone of Ômi-mura in the western part of Echigo: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 8, no. 1, 1924.

[6] Ozawa, Y., Palaeontological and stratigraphical studies on the Permo-Carboniferous limestone of Nagato, Pt. II, Palaeontology: *Coll. Sci. Imp. Univ. Tokyo, Jour.*, vol. 45, art. 6, 1925.

fauna is not found in the Japanese Islands, while the nearly contemporaneous limestone zone of the Akiyoshi district has, according to Ozawa, not only *Dibunophyllum rugosum* M'Coy var. *ofukuense* Ozawa, but also *Lonsdaleia floriformis crassiconus* M'Coy, *Lonsdaleia enormis* Ozawa and *Chaetetes* sp. in common with the lower zone.

Our Permian coral fauna is much simpler, prevailing types being *Waagenophyllum*, *Michelinia* (*Michelinopora*), and *Pachypora*. The Permian limestones of the Akiyoshi district contain several species of corals, and Ozawa distinguished two species of *Lonsdaleia*, s. str.; five species of *Waagenophyllum*, including *Waagenophyllum akasakense* Yabe; and *Chaetetes* sp. Lately we have described a hydrozoan, *Lophiostroma ozawai*.[7] *Waagenophyllum akasakense* Yabe is very common in a zone of the limestone of Akasaka (province of Mino), which is some 600 m. or less by estimated thickness; *Romingeria (?) kotoi* Yabe and Hayasaka, a rare form, also occurs. A hydrozoan, *Stromatopora* (*Parallelopora*) *minoensis* Yabe and Sugiyama, occurs in a lower zone.[8] The same species of *Waagenophyllum* and its close ally, *Waagenophyllum indicum virgalense* Waagen and Wentzel, as well as *Michelinia* (*Michelinopora*) *multitabulata* Yabe and Hayasaka, are very common corals in the Lower Permian of the Kitakami Mountainland, the last species often forming large stocks.

An interesting case of an aggregate growth of two Permian species of *Pachypora* is known from a small rock, Yakejima, off the coast of Obama, Jûgohama-mura, Rikuzen (in the southern part of the Kitakami Mountainland).

Recently J. Iwai, of our Geological Institute, has discovered in the northern part of the Abukuma Mountainland, northeast Japan, a peculiar limestone, full of stromatoporoid remains belonging to the genus *Clathrodictyon*. This rock is in general aspect hardly distinguishable from certain Gotlandian or Devonian stromatoporoid limestones of Europe, though decidedly much younger (Permian).[9]

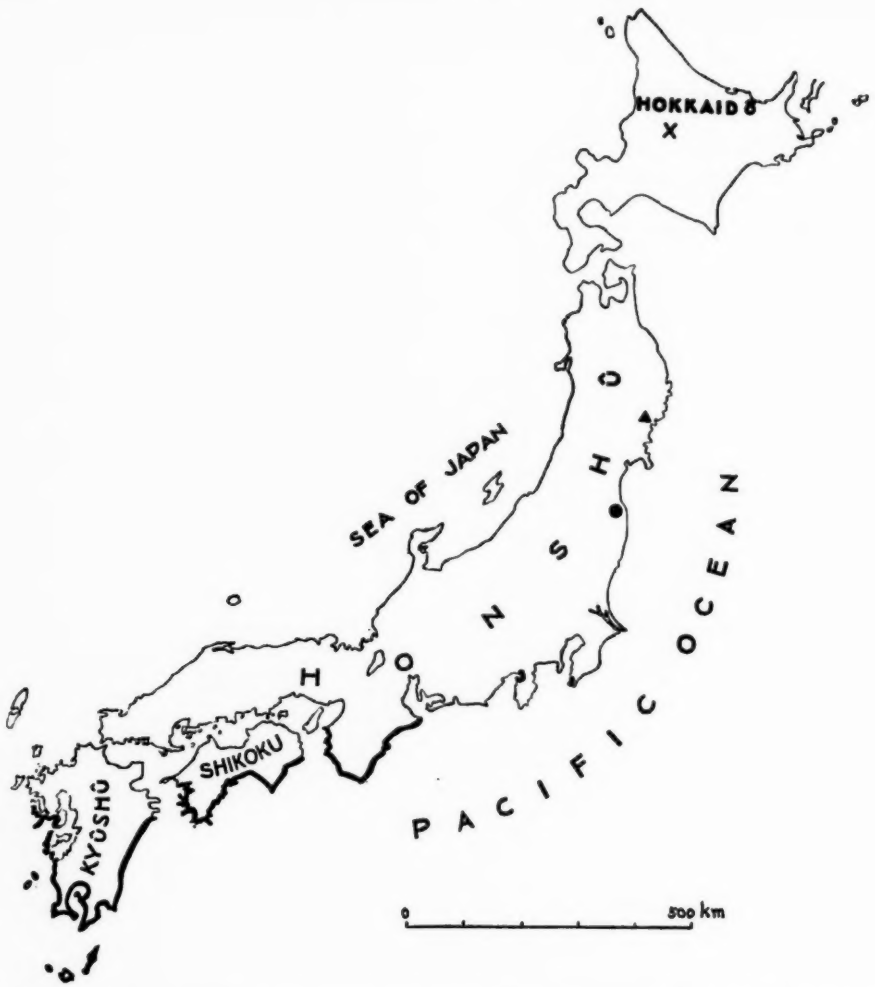
The Kitakami Mountainland (lat. 38°15′ to 40°31′ N.) of northeast Japan is the northernmost tract in the Japanese Islands where colonial corals enjoyed a more or less prolific growth in the Lower Carboniferous and Permian periods (Text-Fig. 1, triangle).[10]

[7] Yabe, H., and Sugiyama, T., Note on a new form of *Lophiostroma* from the Permian of Japan: *Jap. Jour. Geol. Geogr.*, vol. 9, no. 1–2, 1931.

[8] Yabe, H., and Sugiyama, T., Note on a Lower Permian Stromatoporoid from Japan: *Jap. Jour. Geol. Geogr.*, vol. 8, no. 1–2, 1930.

[9] We have now five species of stromatoporoids from the Chichibu system, all found in limestone. Three of them have already been cited above. The other two are *Sphaerostromella shikokuensis* Yabe and Sugiyama, from Shikoku, and *Amphipora* cfr. *A. asiatica* Cowper-Reed, from the northern part of the Abukuma Mountainland. The former is a small subspherical hydrozoan abundant in a limestone of either Upper Carboniferous or Permian age. (See Yabe, H., and Sugiyama, T., Note on a new hydrozoa *Sphaerostromella shikokuensis*, gen. et sp. nov., from the Upper Palaeozoic limestone of Shikoku, Japan: *Jap. Jour. Geol. Geogr.*, vol. 8, no. 2, 1931.) A note on the latter is now in preparation.

[10] *Waagenophyllum virgalense* var. *mongoliense* Grabau is stated to be a dominant fos-




TEXT-FIG. 1—Distribution of the recent reef corals along the coasts of Kiushû, Shikoku, and Honshû (black line), in comparison with the northernmost localities of Lower Carboniferous and Permian (△), Upper Jurassic (○), and Lower Cretaceous (×) reef corals.

Coralline rocks have not yet been discovered in our Triassic formations, which are seldom calcareous. Lower Triassic limestones occur to a very limited extent in the provinces of Iyo and Tosa (both in the Outer Zone of southwest Japan), Musashi and Rikuzen (both in northeast Japan); cephalopods are contained in some of the limestones and lamellibranchs in others, but corals are extremely rare or almost absent. Limestones

sil of the *Waagenophyllum* bed of the Jisu Honguer limestone of Jisu Honguer, Mongolia (Grabau, A. W., *The Permian of Mongolia*, 1931). The locality is situated between 42° and 43° of North Latitude.

and corals are even more negligible elements of our Middle and Upper Triassic rocks.[11]

Our Lower and Middle Jurassic deposits, partly marine and partly terrestrial in origin, are almost free from calcareous rocks. Of corals there are known only two forms, a solitary coral of the genus *Anabacia*,[12] from the Lower Jurassic sandstone of Higashi-Nagano, province of Nagato; and a colonial form of the genus *Latimaeandra*, from the Lower Jurassic *Trigonia*-sandstone of Hosoura, province of Rikuzen (Kitakami Mountainland). On the other hand, the Japanese Islands of Upper Jurassic time seems to have been under climatic conditions favourable for the growth of corals, and coralline limestone is an important element of the Upper Jurassic Torinosu series. The so-called Torinosu limestone of the series, which usually forms small masses or lenses of irregular outline, is at some places massive and at others more or less stratified. It abounds in places in hexacorals, stromatoporoids, milleporoids, milleporelloids, tabulates, and calcareous algae, and it has been sometimes suggested that these organisms formed reefs. The northernmost locality of the Torinosu limestone lies in the northern part of the Abukuma Mountainland, lat. 37°50′ N. (Text-Fig. 1, circle).

Genera of coralline organisms found in the Torinosu limestone are, those with an asterisk being common:

Hexacorals: *Acanthogyra*,* *Amphiastrea*, *Aulastrea*, *Calamophyllia*,* *Cladocoropsis*, *Cladophyllia*, *Comoseris*, *Convexastrea*,* *Dendrogyra*,* *Diplarea*, *Diplocoenia*, *Dimorpharea*, *Dimorphastrea*,* *Hydnophora*, *Isastrea*, *Latimeandrea*, *Leptoria*, *Microsolena*,* *Montlivaultia*, *Orbicella*, *Placocoenia?*, *Pleurosimilia*, *Spongiomorpha* (*Heptastylopsis*),* *Stephanocoenia*, *Stromatomorpha*,* *Stylina*, *Thecosmilia*, *Thamnastrea*.*

Tabulata: *Chaetetopsis*,* *Pachypora*,* and two new genera.*

Hydrozoa: *Actinostromaria*, *Milleporella*, *Milleporidium*,* *Stromatopora* (*Epistromatopora*, *Parastromatopora*),* *Tosastroma*.

An unusual northern extension of warm-water organisms in Japan is shown by *Orbitolina* in the Lower Cretaceous formations. *Orbitolina* beds are developed, though limited in their areal extent, in the province of Ishikari, Hokkaidô, and in the province of Rikuchû (Kitakami Mountainland). The *Orbitolina*-rock exposed at several places along the upper course of the Sorachi-gawa, and at a hill in the northern part of the Asahikawa basin, in the first province, is limestone. That in the second, the Miyako Cretaceous district, is highly calcareous sandstone. In both cases the tests of the Foraminifera form the bulk of the rock and accompany reef corals, calcareous algae, and certain types of or-

[11] Yabe, H., and Sugiyama, T., Note on an Upper Triassic spongiomorphoid coral from Sanpozan, Province of Tosa: *Jap. Jour. Geol. Geogr.*, vol 10, no. 1, 1932; A new form of the Genus *Omphalophyllia* collected from Yamanba near Sakawa-machi, Province of Tosa (Shikoku). Idem.

[12] Yabe, H., and Eguchi, M., *Anabacia cycloliloides* sp. nov. from Japan, with remarks on the Genus *Anabacia*: *Jap. Jour. Geol. Geogr.*, vol. 10, 1933).

ganisms similar to those characterising the Urgonian facies of the Mediterranean Lower Cretaceous. The basal Raga conglomerate of the Miyako Cretaceous has many rolled stocks of hexacorals together with well rounded boulders of older rocks, on which it rests unconformably. The corals belong to the genera *Amphiastrea*, *Astrocoenia*, *Diplarea?*, a new genus,* *Eugyra*,* *Heterocoenia*, *Hydnophora*, *Orbicella*, *Pleurosmilia*, *Thamnastrea*, *Thecosmilia*, *Latiphyllia*,* and *Heliopora* (identified in a preliminary study by M. Eguchi, a member of our Institute). Those with an asterisk are common. The northernmost exposure of the *Orbitolina* limestone is a little north of lat. 43° 53′ N. (Text-fig. 1, ×).

Corals are also abundant in a certain zone of the Lower Cretaceous formation of Ôshima, opposite Kesennuma, province of Rikuzen (Kitakami Mountainland). The coralline rock is a sandy shale, and the corals found in it belong to the genera and subgenera *Astrocoenia*, *Enallohelia*,* *Eugyra*, *Rabdophyllia*, *Thamnastrea*,* *Centrastrea*, *Polyphyllastrea*.

The later Cretaceous deposits are almost, if not entirely, free from limestone as well as stock-building corals. Disc-shaped corals are occasionally found in the Upper Cretaceous (Senonian) deposits of Saghalin and Hokkaidô. They belong to the genera *Cyclocyathus*, *Platycyathus*, and *Trochocyathus*.[13]

In the Japanese Islands, rocks composed of large-sized tests of highly organised Tertiary Foraminifera are very limited in distribution. Beds containing *Camerina* and *Orthophragmina* extend, however, to lat. 32° 30′ N.; those with *Eulepidina* to lat. 30° N.; and those with *Nephrolepidina* and *Miogypsina* to lat. 40° 50′ N. Coral stocks are common in some parts of these foraminiferous rocks, but they rarely aggregate together so densely as to form typical coralline rocks.

An almost unique example of typical coral limestone in the Tertiary of Japan is that very recently found by one of us (Sugiyama) in the limestone series exposed on a small islet Minami-jima, opposite Minami-zaki, the southernmost point of Chichi-jima (Ogasawara Group). The coral limestone is a lithified mass of crowded coral stocks, mostly in upright position and hence probably indicating their growth *in situ*. The limestone series contains *Eulepidina* and is assigned by us approximately to the Aquitanian stage, as stated elsewhere.[14] The identification of the fossil corals has not yet been completed, but the genera *Alveopora*, *Astrocoenia*, *Favia*, *Favites*, *Lamellastrea(?)*,* *Orbicella*,* *Porites*,* and *Psammocora(?)*, are likely to be represented among them.

Many coral stocks are found in a *Nephrolepidina*-bearing limestone exposed near Ôishi, on the north shore

[13] Eguchi, M., Three new turbinarian corals from the Upper Cretaceous of Saghalin and Hokkaidô: To be published in *Jap. Jour. Geol. Geogr.*

[14] Yabe, H., Tertiary rocks with higher Foraminifera from Japan (in Japanese): *Geol. Soc. Tokyo, Jour.*, vol. 27, 1920. Hanzawa, S., Foraminiferal rocks of Okinawa Islands and Ogasawara Islands (in Japanese): *Geol. Soc. Tokyo, Jour.*, vol., 32, 1925.

of the Lake Kawaguchi in the province of Kai. Among the corals collected at this locality we can distinguish several species of the genera *Favia*, *Favites* (*Prionastrea*), *Hydnophyllia*, and *Maeandra*. Two small hills, Megami-yama and Ogami-yama, near Sagara-machi in the province of Tôtômi, are an immense accumulation of coralline algae, Melobesiae and Corallinae in numerous species. This limestone is rather poor in corals, the commonest forms being *Stylophora*, *Mussa*, and *Montipora*. The *Nephrolepidina* limestone of Ôishi is approximately Burdigalian in age and that of Ogamiyama and Megami-yama may be a little younger. The former (lat. 35° 30′ N.) marks the northernmost limit of reef-coral growth in the Japanese Islands during the Tertiary period.

The Riukiu limestone of the Riukiu Islands and Taiwan is a limestone formation of immense extent. It extends over 8 degrees of latitude, occupying widely separate areas be tween the southernmost point of Taiwan, Cape Garambi (lat. 22° N.), and the islands Ô-shima and Kikai-shima of the Ô-shima Subgroup of the Riukiu Islands, (lat. 28° 30′ N.). In thickness it seldom exceeds 80 meters. At most places it is fairly well stratified, often with interbedded foraminiferal limestones. At places it includes massive coralline limestone, composed almost solely of coral stocks—*Porites* at an exposure in a quarry once open near Shuri, Okinawa-jima. In a recent trip to Kikai-shima, S. Hanzawa found numerous coral-stocks weathered out, under favorable conditions, from a coral limestone. These are well preserved and are determined as follows:

*Acanthastrea* cfr. *hemprichii* (Ehr.), *Acropora* sp., *Alveopora* cfr. *verrilliana* Dana, *Antillia japonica* Yabe and Sugiyama, *Astraeopora* cfr. *gracilis* Bernard, *Cyphastrea chalcidicum* Klunzinger, *Cyphastrea microphthalma* (Lam.), *Euphyllia fimbriata* (Spengler), *Favia amplior* (M.-Edw. and H.), *Favia speciosa* (Dana), *Favia valenciennesii* (M.-Edw. and H.), *Hydnophora exesa* (Pallas), *Leptoria phrygia* (Ell. and Soll.), *Maeandra* cfr. *lamellina* Ehr., *Maeandra* cfr. *stricta* (M.-Edw. and H.), *Orbicella curta* Dana, *Orbicella* sp., *Oulophyllia* cfr. *crispa* (Lam.), *Tubipora musica* L.

Most of the Riukiu limestone corals from other localities in our collection are not in good preservation, and difficulty always arises as to specific and generic determinations. The annexed Table 1 shows a list of the Riukiu limestone corals hitherto examined by us, including 68 species in 38 genera. The fossil coral fauna, as a whole, seems to be not much different from the living one of the region concerned.[15]

The precise geological age of the Riukiu limestone is still unsettled. Certainly it is neither younger nor much older than the Pleistocene. It was thought by us to be the youngest Neogene or pre-Pleistocene, partially on the grounds, first, that the large-sized foraminiferal fauna of the

[15] *Tubipora*, *Oulophyllia*, and *Antillia* occur in the Riukiu limestone of the Riukiu Islands, but are not represented in our collection of recent corals from the same islands.

TABLE I.—List of the Reef-Corals from the Riukiu Limestone (Late Pliocene?) of the Riukiu Islands and Taiwan

| SPECIES \ LOCALITIES | RIUKIU | | | | | TAIWAN | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Kikai-shima | Ishigaki-jima | Miyako-jima | Yonakuni-jima | Hateruma-jima | Hanpei-zan | Kotobuki-yama | Taikô-zan | Shôriukiu |
| *Galaxes clavus* (Dana) | — | — | x | — | — | — | — | — | — |
| *fascicularis* (Linné) | — | — | x | — | — | — | — | — | — |
| *Euphyllia fimbriata* (Spengler) | x | — | — | — | — | — | — | — | — |
| *Cyphastrea chalcidicum* Klunzinger | x | — | — | — | — | — | — | — | — |
| *microphthalma* (Lam.) | x | — | — | — | — | x | — | — | — |
| *serailia* (Forskål) | — | — | x | x | — | x | x | — | — |
| *Leptastrea* ? sp. | — | — | x | x | — | — | — | — | — |
| *Orbicella* cfr. *curta* Dana | x | — | — | x | — | — | x | — | — |
| sp. (A) | x | — | — | — | — | — | — | — | — |
| sp. (B) | — | — | x | — | — | — | x | — | — |
| sp. (C) | — | — | — | x | — | — | — | — | — |
| *Favia* cfr. *amplior* (M.-Edw. and H.) | x | — | — | — | — | — | — | — | — |
| cfr. *pallida* (Dana) | — | — | — | x | — | — | — | — | — |
| *speciosa* (Dana) | x | — | x | x | x | — | — | — | — |
| cfr. *speciosa* (Dana) | — | — | — | — | — | x | — | — | — |
| *valenciennesii* (M.-Edw. and H.) | x | — | — | — | — | — | — | — | — |
| sp. (A) | — | — | x | — | — | — | — | — | — |
| sp. (B) | — | — | x | — | — | — | — | — | — |
| *Favites* cfr. *virens* (Dana) | — | — | — | x | — | x | — | — | — |
| sp. (A) | — | — | x | — | — | x | — | — | — |
| sp. (B) | — | — | — | — | — | — | x | — | — |
| ? sp. (C) | — | — | x | — | — | — | — | — | — |
| *Goniastrea parvistella* (Dana) | — | x | — | — | — | — | — | — | — |
| cfr. *pectinata* (Ehr.) | x | — | — | x | — | — | — | — | — |
| *retiformis* (Lam.) | — | — | — | x | x | — | — | — | — |
| ? sp. | — | — | — | — | — | — | — | — | x |
| *Leptoria gracilis* (Dana) | — | — | — | — | — | — | — | — | x |
| *phrygia* (Ell. and Soll.) | x | — | x | x | — | — | — | — | — |
| *te nuis* (Dana) | — | — | x | — | — | — | — | — | — |
| ? sp. | — | — | x | — | — | — | — | — | — |
| *Maeandra astreiformis* M.-Edw. and H | — | — | — | — | — | — | x | — | — |
| cfr. *lamellina* Ehr. | x | — | — | — | — | — | — | — | — |
| cfr. *stricta* (M.-Edw. and H.) | x | — | — | — | — | — | — | — | — |
| ? sp. | — | — | x | — | — | — | — | — | — |
| *Hydnophora exesa* (Pallas) | x | — | — | — | — | — | — | — | — |
| *microconos* Lam. | — | — | x | — | — | — | — | — | — |
| sp. (A) | — | — | x | — | — | — | — | — | — |
| sp. (B) | — | — | x | — | — | — | — | — | — |
| *Hydnophyllia* ? sp. | — | — | — | — | — | x | — | — | — |
| *Antillia japonica* Yabe and Sugiyama | x | — | — | — | — | — | — | — | — |
| ? sp. (A) | — | — | — | — | — | x | — | — | — |
| ? sp. (B) | — | — | — | — | — | — | — | x | — |
| *Fungia cyclolites* Lam. var. | x | — | — | — | — | — | — | — | — |
| cfr. *granulosa* Klunzinger | — | x | — | — | — | — | — | — | — |
| sp. (A) | — | x | — | — | x | — | — | — | — |
| sp. (B) | — | — | — | x | — | — | — | — | — |
| *Oulophyllia* cfr. *crispa* (Lam.) | x | — | — | — | — | — | — | — | — |
| *Mussa* ? sp. | — | — | x | — | — | — | — | — | — |
| *Symphyllia* ? sp | — | — | — | x | x | — | — | — | — |
| *Acanthastrea* cfr. *hemprichii* (Ehr.) | x | — | — | — | — | — | — | — | — |

TABLE I. (*Continued*)

| SPECIES \ LOCALITIES | RIUKIU | | | | | TAIWAN | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Kikai-shima | Ishigaki-jima | Miyako-jima | Yonakuni-jima | Hateruma-jima | Hanpei-zan | Kotobuki-yama | Taikô-zan | Shôriukiu |
| *Coscinarea* ? sp. | — | — | x | — | — | — | — | — | — |
| *Pavona* sp. | — | — | — | — | — | — | — | — | x |
| *Pachyseris* cfr. *rugosa* (Lam.) | — | — | x | — | — | — | — | — | — |
| cfr. *speciosa* (Dana) | — | — | — | — | — | x | — | x | — |
| *Turbinaria* sp. | — | — | — | — | — | — | — | x | — |
| *Astraeopora* cfr. *gracilis* Bernard | x | — | — | — | — | — | — | — | — |
| *Goniopora* sp. (A) | — | x | — | — | — | — | — | — | — |
| sp. (B) | — | — | — | x | — | — | — | — | — |
| sp. (C) | — | — | — | — | — | x | — | — | — |
| *Acropora* sp. (A) | — | — | x | — | — | — | — | — | — |
| sp. (B) | — | — | — | x | — | — | — | — | — |
| sp. (C) | x | — | — | — | — | — | — | — | — |
| *Porites* sp. (A) | — | — | x | — | — | x | — | — | — |
| sp. (B) | — | — | x | — | — | — | — | — | — |
| *Alveopora* cfr. *verrilliana* Dana | x | — | — | — | — | — | — | — | — |
| sp. | — | — | x | — | — | — | — | — | — |
| *Tubipora musica* L. | x | — | x | x | — | — | — | — | — |

limestone has several features distinct from the present fauna of the same region and approaches that of more southern seas; second, that the deposition of such an extensive calcareous formation by direct or indirect contribution of organisms identical with those which now haunt the tropical and subtropical seas is hardly expectable during the Pleistocene. We have no good reason at present to believe that a climate warmer than that of the present prevailed over the Japanese Islands during the Pleistocene. On the other hand, we have no positive evidence against the view that the limestone may be a product of one, especially an earlier one, of the interglacial stages. Other collateral evidence, however, geological and morphological data from the Riukiu Islands and Taiwan, derived from the peculiar configuration of the adjacent sea bottom, the extensive submerged surfaces at 2 different levels, seem to be more favorable to the assumption of youngest Pliocene age for the Riukiu limestone.[16]

We can not close this chapter without again referring to the important role of calcareous algae in our geological formations, for they took an important part in the building of limestones, in association with corals and Foraminifera. To mention conspicuous examples, there are *Mizzia japonica* Karpinsky (?= *Mizzia velebitana* Schubert) in the Permian; *Solenopora rothpletzi* Yabe, *Nipponophycus ramosus* Yabe and Toyama,

[16] Yabe, H., and Hanzawa, S., A geological problem concerning the raised coral reefs, etc.: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 7, no. 2, 1925.

*Pycnoporidium lobatum* Yabe and Toyama, *Girvanella tosaensis* Yabe and Toyama in the Upper Jurassic (Torinosu limestone); *Nipponophycus ramosus* Yabe and Toyama, *Stenoporidium chaetetiformis* Yabe and Toyama, *Petrophyton miyakoense* Yabe in the Lower Cretaceous. Melobesiae, Corallinae and *Halimeda* were active in the construction of some of our Tertiary limestones already mentioned in the foregoing paragraphs, as they are for the building of reef rocks in the present tropical and subtropical seas.[17]

## II. PLEISTOCENE DEPOSITS

In the northern and middle parts of Taiwan, plateau gravel covered by red lateritic earth is unconformably underlain by two Neogene series, the Shokkôzan and Byôritsu, whereas in the southern part it is underlain by the youngest Neogene Riukiu limestone.[18] The plateau gravel is barren of marine fossils, though mammalian remains are occasionally found in it. Very similar plateau gravel occurs also on Okinawa-jima and several other islands of the Riukiu group, and Hanzawa believes it contemporaneous with that of Taiwan.[19] Both plateau gravels may possibly be terrestrial sediments either of the "Latest Continental Stage" of the Japanese Islands, transitional from the Pliocene to the Pleistocene, or of the Pleistocene, or of both of them.[20]

A representative example in the main island (Honshû) of Pleistocene marine deposits is the Narita series of the Kwantô region, while one of terrestrial origin is the fossil lake deposit of Shiobara, in the volcanic district of the same name in the Shimotsuke Mountainland.[21]

The Narita series admits of numerous minor subdivisions according to the nature of sediments and of the faunas they contain. These can be grouped into 3 larger divisions; the upper Narita, or Narita proper, is conformable on the middle Narita, or Kiyokawa group, which in turn rests

[17] Nishiwada, K., On some organic remains from the Tertiary limestone near Sagara, Tôtômi: *Coll. Sci. Univ. Tokyo, Jour.*, vol. 7, pt. 3, 1894. Yabe, H., Ueber einige Gesteinbildende Kalkalgen von Japan und China: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 1, no. 1, 1912. Yabe, H., andToyama, S., On some rock-forming algae from the younger Mesozoic of Japan: *Idem*, vol. 12, no. 1, 1928.

[18] Yabe, H., and Hanzawa, S., Tertiary foraminiferous rocks of Taiwan (Formosa): *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 14, no. 1, 1930; Stratigraphical studies of the Tertiary foraminiferous rocks of Taiwan (in Japanese): *Memorial Volume for the 60th Birthday Celebration of Professor T. Ogawa*, 1929.

[19] It was stated by Yabe and Hanzawa in 1930 that in Okinawa-jima, the plateau gravel is older than the Riukiu limestone. Recent observations of Hanzawa have shown that the former is actually younger than the latter, just as in Taiwan. A conglomerate underlying the Riukiu limestone is now proved to be different from the plateau gravel. The Cenozoic stratigraphy of the Riukiu Islands and Taiwan are thus no longer discrepant.

[20] The plateau gravel is often difficult to separate from certain gravel beds of younger terraces in the valleys incised through the plateau, and a part of what we now call plateau gravel may better be separated from the typical deposit.

[21] Yabe, H., Relation of the volcano Shiobara to the local geotectonic (in Japanese): *Jap. Assoc. Adv. Sci., Proc.*, vol. 4, 1928.

unconformably on the lower Narita, or Sanuki with Sasage sand and gravel at the base.[22]

The molluscan fauna as a whole is very rich in cool water elements or northern types. A number of warm water elements or southern types are found in the lower Narita, or Sanuki, subfauna, whereas nearly all of them disappear in the middle Narita, or Kiyokawa, subfauna. In the upper Narita subfauna, northern types are slightly reduced in number, as compared with the Kiyokawa, but not so much as in the Sanuki. In short, the lowering of the temperature of sea water reached its climax in the middle Narita time.

Plant remains are abundant in the fossil lake deposits of Shiobara, more than 65 species being discriminated, most of them broad-leaved plants. All the specifically determined forms are still living in Japan. The fossil vegetation differs from the present one in the vicinity of the fossil lake, but is very similar to that around the well known Lake Chûzenji of Nikkô, another volcanic district lying to the south of Shiobara. Lake Chûzenji has an altitude of 1500 m. above the present sea level, being at least 800 m. higher than the site of the fossil lake.

The Shimotsuke Mountainland, with the two volcanic districts of Shiobara and Nikkô, is bordered on the east by the broad platform of eastern Shimotsuke incised by the valleys of the Naka-gawa and the Kinu-kawa, which discharges its water into the Tone-gawa near the center of the Kwantô tectonic basin. River terraces well developed along the border of the mountainland descend gently southwards to the uplifted platform of the basin, through which they can be traced more or less continuously to the coastal land. It is therefore thought possible to make by estimation a rough approximation of the altitude of the site of the fossil lake of Shiobara above the sea-level of the past age, and the result of our trial is some 500–600 meters.

The uplifted platform of the tectonic basin is built in greater part of the marine sediments of the Narita series, as well as its equivalent, the marine Tokyo series; and in lesser part of contemporaneous semiterrestrial deposits in the marginal belt of the basin. The surface layer, resting unconformably upon the foundation rocks of the platform, is the Kwantô loam, which also covers the surface of the higher river terraces of the Kinu-kawa. Consequently the terraces on the eastern border of the Shimotsuke Mountainland can be called in to aid in a chronological correlation between the fossil lake deposits of Shiobara on one side and the marine Narita of the Kwantô region on the other side. Apart from palaeontological data, the approximate contemporaneity of the former at least to a part (the upper) of the latter is believed to be manifest.

All the facts stated above agree in

[22] In the guide-book for excursion C6 of the 3rd Pacific Science Congress, the Narita series was divided into two. Recent progress of our stratigraphical knowledge has shown that three divisions of it mentioned above are more practically convenient.

respect to the geographical condition of the Japanese Islands during the Pleistocene: namely, the land as a whole was probably lower and the climate was cooler than now.

By future detailed studies of the fossils from the different zones of the Narita series, it will be possible to bring out evidence of faunal changes reflecting those of climate during the alternate glacial and interglacial stages of the glaciated areas.

Corals found in the Narita and Tokyo series are few, all being either solitary forms or simply branching colonies of relatively deeper waters. They are *Balanophyllia* sp., *Caryophyllia* sp., *Ceratotrochus* sp., *Deltocyathus lens* Alcock, *Deltocyathus* sp., *Dendrophyllia* sp., *Discotrochus ?* sp., *Flabellum transversale* Moseley and var. *kazusaense* Yabe and Eguchi, *Endopachys japonicum* Yabe and Eguchi, *Heterocyathus* sp., *Oulangia stockesiana* (Milne-Edwards and Haime) var. *miltoni* Yabe and Eguchi, *Sabinotrochus?* sp., and *Stephanophyllia fungilus* Alcock.[23]

## III. POST-PLEISTOCENE CORALLINE DEPOSITS

Post-Pleistocene raised coral reefs and raised beach deposits with corals are recorded by Hanzawa from various places in Taiwan, and are also well developed in the Riukiu Islands.

The raised coral reefs are well developed along the coast of the southernmost part of Taiwan, as well as around the coast of the small islets Kôtô-sho, Kashô-tô and Shôriukiusho; everywhere they assume a former coastal terrace: besides, they are feebly developed on the raised abrasion benches near Kiirun and Cape Fukkikaku in the northernmost part of Taiwan. On an average, the coastal terraces of raised coral reefs are 100 m. wide and 15 m. high whereas the reefs themselves are 3 m. or slightly more thick. The raised reefs are essentially composed of the stocks of reef corals mostly in upright position and have in association Mollusca, Bryozoa, Foraminifera and calcareous algae; all the organic remains are usually excellently preserved, though sometimes metamorphosed almost to a coralline limestone. On the other hand, layers of calcareous sand and shingles are rare.[24]

At other places, the raised coral reefs are replaced by abrasion platforms with or without a thin cover of raised beach deposit with coral shingles.

In another paper the same author stated that all the islands of the Yaeyama subgroup of the Riukiu Islands are encircled by narrow terraces, some 5 m. high, covered at places by a thin beach deposit of coral sand or shingles and foraminiferal sand.[25] In his recent visit to Kikai-shima and Amami-Ô-shima of the Ôshima subgroup he found

[23] Yabe, H., and Eguchi, M., Some Recent and fossil corals of the Genus *Stephanophyllia* H. Michelin from Japan: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 15, no. 2, 1932; A new species of *Endopachys, Endopachys japonicum* from a younger Cenozoic deposit of Japan: *Jap. Jour. Geol. Geogr.*, vol. 10, no. 1, 1933; Fossil and Recent *Flabellum* from Japan: To be published in *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*; Fossil and Recent *Deltocyathus* and *Discotrochus* from Japan: *Jap. Jour. Geol. Geogr.*

[24] Hanzawa, S., Notes on the raised coral reefs and their equivalent deposits in Taiwan (Formosa) and adjacent islets: *Rec. Oceanogr. Wks. Japan*, vol. 3, no. 2, 1931.

[25] Hanzawa, S., A brief sketch of the geology and geological history of the Yaeyama subgroup (in Japanese): *Geogr. Review, Tokyo*, vol. 8, no. 2, 1932.

TABLE II.—List of the Reef-Corals from the Raised Coral Reefs and Raised Beach Deposits of the Riukiu Islands and Taiwan

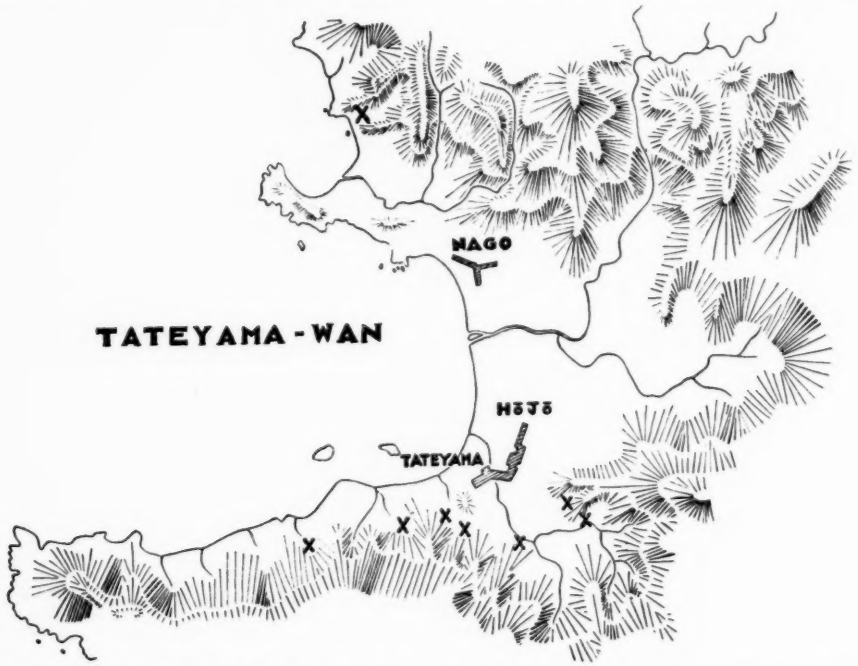
| SPECIES \ LOCALITIES | RIUKIU: Sakishima subgroup | RIUKIU: Kikai-shima | TAIWAN |
|---|---|---|---|
| *Stylophora imperatoris* Vaughan | — | — | x |
| *pistillata* (Esper) | — | — | x |
| sp. | — | x | — |
| *Pocillopora informis* Dana ?. | — | — | x |
| cfr. *maeandrina* Dana var. *nobilis* Verrill? | — | x | — |
| sp. | — | — | x |
| *Galaxea* | | | |
| *clavus* (Dana) | — | — | x |
| *fascicularis* (L.) | x | x | x |
| *Cyphastrea* | | | |
| *chalcidicum* Klunzinger | — | x | x |
| cfr. *gardineri* Matthai | — | — | x |
| *serailia* (Forskål) | — | — | x |
| *microphthalma* (Lam.) | x | x | — |
| *Orbicella* | | | |
| *curta* Dana | — | x | — |
| spp. | x | x | — |
| *Favia* | | | |
| *magnistellata* M.-Edw. and H. | — | x | — |
| *pallida* (Dana) | — | — | x |
| *speciosa* (Dana) | x | x | x |
| *valenciennesii* (M.-Edw. and H.) | — | x | — |
| sp. | — | — | x |
| *Favites* | | | |
| *abdita* (Ell. and Soll.) | — | — | x |
| *virens* (Dana) | — | — | x |
| sp. | — | — | x |
| *Goniastrea* | | | |
| *pectinata* (Ehr) | — | x | x |
| *planulata* M.-Edw. and H. | — | — | x |
| *reliformis* (Lam.) | — | — | x |
| sp. | — | — | x |
| *Leptoria* | | | |
| *phrygia* (Ell. and Soll.) | — | x | x |
| cfr. *tenuis* (Dana) | — | — | x |
| sp. | — | — | x |
| *Maeandra* | | | |
| *astreiformis* M.-Edw. and H. | — | — | x |
| *daedalea* (Ell. and Soll.) | x | — | — |
| *lamellina* Ehr. | — | x | — |
| cfr. *sinensis* M.-Edw. and H. | — | — | x |
| cfr. *stricta* (M.-Edw. and H.) sp. | — | x | — |
| *Hydnophora* | | | |
| *microconos* (Lam.) | — | x | — |
| *exesa* (Pallas) | — | — | x |
| *Fungia* | | | |
| *cyclolites* Lam. var. | — | x | — |
| cfr. *granulosa* Klunzinger | x | — | x |
| cfr. *paumotensis* Stutchberg | x | — | — |
| *Herpetolitha* | | | |
| cfr. *stricta* (Dana) | — | — | x |
| *Coelocoenia* | | | |
| cfr. *vacua* Gerth | — | — | x |
| ? sp. | — | — | x |
| *Symphyllia* | | | |
| cfr. *cactus* Quelch | x | — | — |
| cfr. *nobilis* (Dana) | — | x | — |
| *Oulophyllia* | | | |
| cfr. *aspera* Quelch | — | x | — |
| *Acanthastrea* | | | |
| *echinata* (Dana) var. ? | — | x | — |
| *hemprichii* (Ehr.) | — | x | — |
| *Agaricia* | | | |
| cfr. *forskâli* M.-Edw. and H. | — | — | x |
| *Pachyseris* | | | |
| cfr. *speciosa* (Lam.) | — | — | x |
| *Pavona* | | | |
| sp. | x | — | — |
| *Podabacia* | | | |
| sp. | — | — | x |
| *Coeloseris* | | | |
| sp. | — | — | x |
| *Astraeopora* | | | |
| cfr. *gracilis* Bernard | — | x | — |
| *Turbinaria* | | | |
| *peltata* (Esper) | — | x | — |
| sp. | — | — | x |
| *Goniopora* | | | |
| sp. | — | x | — |
| *Montipora* | | | |
| *sinensis* Bernard | — | — | x |
| cfr. *informis* Bernard | — | — | x |
| cfr. *ramosa* Bernard | x | — | — |
| spp. | — | x | x |
| *Acropora* | | | |
| cfr. *haimei* (M.-Edw.) | x | — | — |
| *hebes* (Dana) | x | — | — |
| cfr. *muricata* (L.) | x | — | — |
| *pulchera* (Brook) | — | — | x |
| *smithi* Brook | — | x | — |
| spp. | x | x | x |
| *Porites* | | | |
| cfr. *compressa* forma *tumida* Vaughan | — | — | x |
| cfr. *lanuginosa* Studer | — | — | x |
| sp. | — | x | — |
| *Alveopora* | | | |
| cfr. *verrilliana* Dana | — | x | — |
| *Heliopora* | | | |
| *caerulea* M.-Edw. and H. | — | — | x |

raised coral reefs well developed around the former island to a breadth of about 1 km., and raised abrasion benches, 1 to 2 m. above the high water mark, around the latter.

The corals of these young geological formations of Taiwan and the Riukiu Islands are listed in Table 2; they belong to 31 genera and constitute a fauna quite indistinguishable from the Recent fauna of the adjacent seas.[26]

To the north of the Riukiu Islands there exist no more raised coral reefs except the remarkable growth of semifossil reef corals at Noma, near Tateyama, in the province of Awa (Honshû), approximately lat. 35° N. On the other hand one good example of raised beach deposits with coral shingle is observable at Mera, a little west of Tanabe, province of Kii.

The coral bed, or more correctly, coral reef, of Noma near Tateyama on the coast of the Tateyama-wan, one of the 15 m. beaches, is the most instructive of all. There an alluvial plain has its surface some 20 m. higher than the present sea level. Many excavations at Okanoma and several other places nearby have shown that there is in a more or less extended distribution beneath the alluvial silt an incipient fringing reef or reef corals that grew in drowned




TEXT-FIG. 2—Extent of the raised coral reef of Noma near Tateyama (×). 1:200,000.

[26] *Oulophyllia* occurs in the coral fauna of the raised coral reefs of Kikai-shima. It is also found in the Riukiu limestone fauna as stated sbove. It is, however, not represented in our collection of recent corals from the Riukiu Islands.

valleys cut into Neogene rocks at the time of the last submergence of the Japanese Islands.

The semifossil coral reef is 2 to 3 m. thick and consists of coral heads or stocks in upright position, the basal stocks resting directly on the rocky floor (Neogene tuffs of the Miura series), or on angular and subangular blocks of the same rocks torn from the floor, and more or less rolled.

Other common organic remains in association with these corals are thick-shelled Mollusca, found in fresh condition, often with color pattern, the bivalves having both valves usually intact. The corals are likewise well preserved, even delicate spinules of the septal margins usually showing no trace of damage. Worthy of special note is further the circumstance that there are almost no rolled coral stocks around the reefs; at least these were not seen in an excavation at Okanoma which Yabe had an opportunity personally to examine a score of years ago, and in another one very recently opened by members of our Geological Institute. All these facts seem to support the view that we have here an incipient fringing reef grown in rather calm water immediately after the land submerged. Subsequent copious settling of mud at the heads of the submerged valleys, and probably also the simultaneous slight lowering of the temperature of the sea water, soon prevented further growth of the coral reefs, and the mud penetrated and filled up the interspaces between the coral stocks.

There is divergence of opinion as to the geological age of the semifossil coral reef of Noma. M. Yokoyama at first maintained a Pleistocene warm age, instead of glacial, in Japan on the evidence of this coral bed, but later assigned it to the youngest Pleistocene. In our opinion[27] it is post-Pleistocene (early Holocene), nearly equivalent to the Neolithic beaches of England.

S. Nomura distinguished 470 species of Mollusca from the raised beach deposits in the Kwantô region, including the semifossil coral reef of Noma, and concluded "the temperature of the sea-water in the time when the raised beach deposits were laid down may have been nearly as warm as that of Central Japan at present; at the most, it may have been as warm as the present coast of Kii, being in no way warmer." As to the geological age of them, he stated, "from the faunal and climatological as well as from the geographical situation, the raised beach deposits seem to have been laid down in the youngest age, ranging from the Neolithic time to the early historic age—the Holocene.[28]

Corals obtained from the semifossil reef are listed on Table 3.[29]

[27] Yokoyama, M., Climatic changes in Japan since the Pliocene Epoch: *Coll. Sci. Univ. Tokyo, Jour.*, vol. 32, art. 5, 1911; Mollusca from the coral bed of Awa: *Idem.*, vol. 45, art. 1, 1924. Yabe, H., Recent stratigraphical and palaeontological studies of the Japanese Tertiary: *First Pan-Pac. Sci. Congr., Proc.*, vol. 3, 1921.

[28] Nomura, S., Mollusca from the raised beach deposits of the Kwantô Region: *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 15, no. 2, 1932.

[29] These semifossil corals, as well as Recent ones, from Japan will be described in a series

TABLE III.—REEF-CORALS FROM THE RAISED CORAL REEF OF NOMA AND THE RAISED BEACH DEPOSIT OF MERA

| SPECIES \ LOCALITIES | HONSHÛ | |
|---|---|---|
| | Noma | Mera |
| *Stylophora* cfr. *danae* M.-Edw. and H. | x | x |
| sp. | x | — |
| *Pocillopora damicornis* (Pallas) | x | — |
| *Cyphastrea chalcidicum* Klunzinger | x | x |
| *japonica* Yabe and Sugiyama nov. sp. | x | — |
| *serailis* (Forskål) | x | — |
| *Leptastrea purpurea* (Dana) | x | ? |
| *Echinophyllia* spp. | x | x |
| *Orbicella* cfr. *felixi* Gerth | x | — |
| *versipora* (Lam.) | x | ? |
| sp. | x | — |
| *Favia magnistellata* M.-Edw. and H. | x | — |
| *pallida* (Dana) | x | — |
| *speciosa* (Dana) | x | x |
| *Favites abdita* (Ell. and Soll.) | x | — |
| *virens* (Dana) | x | — |
| *Maeandra astreiformis* M.-Edw. and H. | — | x |
| sp. | x | — |
| *Hydnophora exesa* (Pallas) | x | x |
| *Antillia constricta* Brüggeman | x | — |
| *japonica* Yabe and Sugiyama | x | — |
| *nomaensis* Yabe and Sugiyama sp. | x | — |
| *Fungia* cfr. *patella* (Ell. and Soll.) | x | — |
| *Caulastraea yokoyamai* Yabe and Sugiyama | x | — |
| *yokoyamai* Yabe and Sugiyama var. *gracilis* Y. and S. | x | x |
| *Mussa* cfr. *regalis* Dana | x | — |
| *Tridacophyllia* sp. | x | x |
| *Acanthastrea hemprichii* (Ehr.) | x | — |
| *Psammocora paponica* sp. nov. | x | — |
| *profundacella* Gardiner | x | x |
| *superficialis* Gardiner | x | — |
| *Coscinarea* sp. nov. | x | — |
| *Pavona danae* M.-Edw. and H. | x | — |
| spp. | x | — |
| *Podabacia lobata* Van der Horst | x | ? |
| *lobata* forma *nomaensis* Yabe and Sugiyama | x | — |
| *lobata* forma *vanderhorsti* Yabe and Sugiyama | x | — |
| *Turbinaria contorta* Bernard | x | ? |
| *peltata* (Esper) | x | x |
| *Goniopora* sp. | x | — |
| *Montipora* cfr. *ramosa* Bernard | x | — |
| *Acropora* sp. | x | x |
| *Porites* cfr. *bernardi* Vaughan | x | — |
| cfr. *hawaiensis* Vaughan | x | — |
| *Alveopora* cfr. *verrilliana* Dana. | x | — |
| Gen. sp. indet | x | — |

They belong to 46 species in 27 genera, excluding one generically as well as specifically indeterminable form, of excellent preservation, which is rare and represented by a single specimen. Dominant above all is *Favia speciosa;* next are *Caulastraea yokoyamai* and variety, *Cyphastrea chalcidicum*, *Echinophyllia* sp., *Leptastrea purpurea*, *Orbicella* sp., *Podabacia lobata* and varieties, and *Turbinaria contorta*. The generically indeterminable form excluded, nearly all the species are now living in the adjacent seas. A comparison of this fauna with the Recent one of the adjacent seas brings out the following result: no coral of the genus *Coscinarea* was found in our collection of Recent corals from Honshû and Shikoku, though living in the seas of the Riukiu Islands and Ogasawara-jima. Of the genus *Fungia*, we have only 1 species, *Fungia cyclolites*, from the adjacent seas, while *Fungia patella* is not yet known living in the Riukiu Archipelago and north. *Pocillopora* is richly represented by only 1 species in the seas of Misaki (Shikoku) and Kushimoto (Kii), but very poorly in the Noma fauna. Finally, most characteristic of it is the absence of *Goniastrea* and the great rarity of *Montipora*, *Acropora* and *Porites* in it as compared with the abundance of species of these genera in the adjacent seas.

The beach deposit of Mera is far less important. Some 2 km. west of Tanabe, province of Kii, there is the

of papers under the title *A study of Recent and semifossil corals of Japan*, of which the first part (*Antillia* and *Caulastraea*) has already been published in *Sci. Rep. Tôhoku Imp. Univ., Geol. Ser.*, vol. 14, no. 2A, 1931.

small peninsula of Mera. In the upper 1.5 to 2 m. of a 5 m. sea-cliff cut into a low terrace is exposed a beach deposit of sand and clay with shingles 2–3 cm. in diameter, which rests unconformably on the abraded surface of the underlying Neogene sandstones. Molluscan shells and coral shingles are common in the beach deposit. The corals specifically discriminated are listed in Table 3. They represent 15 species in 14 genera, including 4 doubtful ones. All the species are living now in the Tanabe-wan, as mentioned in the next chapter, and also occur in the Noma reef.

## IV. REEF CORALS FOUND IN THE JAPANESE SEAS

A list of the reef corals in the Japanese seas is given in Table 4. The specific determination is rather tentative in certain forms and these will be revised later. The first step of our study was to make a rapid reconnaissance of the general aspect of the fauna as to its constituents.[30] The present list is by no means complete, because the number of collecting grounds visited by our collaborators is limited, and the collection made in many cases is far from being exhaustive; among others, we felt particularly the deficiency of material from Taiwan and some other semitropical islets of Japan. The present list of corals will certainly be much enlarged by acquisition of new materials.

The collecting grounds for reef corals visited by our collaborators may be grouped in the 22 fields enumerated below:

Pacific coast of Honshû (the Main Island: Tateyama-wan, Enoura-wan, Yura-wan, Tanabe-wan, Kushimoto.

Pacific coast of Shikoku: Murotozaki, Tei, Susaki, Misaki (all in the province of Tosa), Uwajima-wan.

Kiushû and dependent islets: coast of Hiuga, coast of Ôsumi, Kagoshima-wan, southern coast of Satsuma, coast of Hizen, Amakusa, Koshiki-jima.

Riukiu Group: Ôshima, Okinawa, and Sakishima subgroup.

Ogasawara Group: Chichi-jima, and Haha-jima.

Taiwan (Formosa): Sharyô-tô near Taihoku.

The geographical distribution is shown on the Text-Figure 1.

In the Japanese Islands, the reef corals are growing on rocky sea bottoms along coasts submerged in post-Pleistocene time. In the Enoura-wan and Tateyama-wan as well as in the somewhat southerly Tanabe-wan of Kii Peninsula, the coral stocks are never crowded and rarely overgrown one upon another. They are found at depths from 5 to 40 m., and are never exposed, even at the low spring tide. In the southern part of Kiushû, on the other hand, the coral stocks are more or less densely crowded, at places entirely covering the rocky sea bottoms, but never assuming a reef-like structure. Their growth ex-

[30] Yabe, H., and Sugiyama, T., Reef building coral fauna of Japan: *Imp. Acad., Proc.*, vol. 7, no. 9, 1931; Reef corals found in the Japanese seas: *Sci. Rep Tôhoku Imp. Univ., Geol. Ser.*, vol. 15, no. 2, 1932.

TABLE IV.—LIST OF THE REEF-CORALS FOUND LIVING IN THE JAPANESE SEAS

| SPECIES \ LOCALITIES | HONSHÛ | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. Coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| *Stylophora* cfr. *danae* M.-Edw. and H. | – | x | – | x | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – |
| *pistillata* (Esper) | – | – | – | – | – | – | – | – | x | – | x | – | – | x | – | – | – | – | – | x | – |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| nov. sp. ? | x | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Seriatopora angulosa* Klunzinger | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *hystrix* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – |
| *Pocillopora damicornis* (Pallas) | – | – | – | – | x | – | – | – | x | – | x | x | x | x | – | – | – | – | – | x | x |
| *damicornis* var. *cespitosa* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | x | – | – |
| *ligulata* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| cfr. *elegans* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *maeandrina* Dana var. *nobilis* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x |
| *modumanensis* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *verrucosa* (Ellis and Sollander) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *Galaxea fascicularis* (L.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | x | x |
| *clavus* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| *Euphyllia fimbriata* Spengler | – | – | – | – | – | – | – | – | x | – | x | – | – | x | – | x | – | – | x | x | x | x |
| *glabrescens* (Chamisso and Eysenhardt) | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *Cyphastrea chalcidicum* Klunz. incl. C. *ocellina* (Dana) | – | x | x | x | x | x | – | x | x | – | x | – | x | x | x | x | x | – | x | – | x | – |
| *chalcidicum* var. *tanabensis* Y. and S. nov. | – | – | x | x | x | – | – | – | – | x | – | – | x | – | x | – | – | – | – | – | – | – |
| *japonica* Y. and S. nov. sp. | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *microphthalma* (Lam.) | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – | – | – | – |
| *serailia* (Forskål) | – | x | – | x | x | x | x | – | – | x | – | – | x | x | – | – | – | x | – | x | x | – |
| cfr. *gardineri* Matthai | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| *Stylocoenia japonica* Y. and S. nov. sp. | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Leptastrea purpurea* (Dana) | x | x | – | x | x | x | – | x | x | – | x | – | x | x | – | x | – | – | – | – | x | x |
| *Echinopora lamellosa* (Esper) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *Echinophyllia* cfr. *contorta* (Quelch) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| sp. A | – | x | x | x | x | – | – | x | x | x | x | – | – | x | x | x | x | – | x | – | – | – |
| sp. B | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Orbicella curta* Dana | – | – | – | – | x | – | x | – | – | – | – | – | – | x | – | – | – | – | – | – | x | x |
| *gravieri* Vaughan | – | – | – | x | – | – | – | – | – | x | – | – | – | – | x | x | – | – | – | x | – | – |
| cfr. *praehaliopora* Gregory | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – |
| *versipora* (Lam.) | – | – | – | x | – | – | x | x | x | – | x | – | x | x | x | – | – | – | – | – | – | – |
| sp. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | x | – | – |
| *Favia* cfr. *amplior* (M.-Edw. and H.) | – | x | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | x | x |
| cfr. *danae* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *magnistellata* M.-Edw. and H. | – | – | x | x | – | x | x | x | x | x | x | – | x | x | – | – | – | – | – | x | x | – |
| cfr. *matthai* Vaughan | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *speciosa* (Dana) | – | x | – | – | – | x | – | x | – | x | x | – | – | – | – | x | – | – | x | – | x | x |
| *pallida* (Dana) | – | x | x | x | x | x | – | x | – | x | – | – | – | x | x | – | – | x | – | x | x | |

A = RIUKIU; B = TAIWAN; C = OGASAWARA GROUP

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHÛ | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| *Favites abdita* (Ellis and Sollander) | – | x | – | – | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – | – | – | – |
| *virens* (Dana) | – | – | – | – | – | – | – | – | x | – | x | – | – | x | – | – | – | – | x | – | – | – |
| sp. | – | – | – | – | – | – | – | – | x | – | x | – | – | x | – | – | – | – | – | – | – | – |
| *Goniastrea aspera* Verrill | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | x | – | – | – | – |
| *parvistella* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *pectinata* (Ehrenberg) | x | x | – | – | x | x | x | x | x | x | – | – | – | – | – | x | – | x | x | – | x | x |
| *retiformis* (Lam.) | – | – | – | – | x | – | x | x | x | – | x | – | – | x | – | – | x | – | x | – | x | – |
| sp. | – | – | – | – | x | – | x | x | x | – | x | – | – | x | – | – | – | – | – | – | – | – |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *Leptoria gracilis* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| *phyrygia* (Ellis and Sollander) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| sp. nov. ? | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *Maeandra daedalea* (Ellis and Sollander) | – | – | – | x | x | – | x | – | x | – | x | – | x | x | – | – | – | ? | – | – | x | – |
| *edwardsi* (Gardiner) | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – | – | – | x | – |
| *esperi* (M.-Edw. and H.) | – | – | – | – | x | – | x | x | x | x | x | – | – | x | – | x | – | – | – | – | – | – |
| *lamellina* Ehrenberg | – | x | – | x | x | x | ? | x | x | – | x | x | – | – | – | x | x | – | x | – | x | x |
| *stricta* (M.-Edw. and H.) | – | – | – | x | x | – | – | – | x | – | – | – | – | – | – | – | – | – | x | – | x | – |
| sp. A | – | – | – | – | x | – | – | – | x | – | – | – | – | x | – | – | – | – | – | – | – | – |
| sp. B | – | x | – | – | – | – | – | – | x | – | – | – | – | – | x | – | – | – | – | – | – | – |
| sp. C | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | x | – | – | – | – | – |
| sp. D | – | x | – | x | x | – | – | – | – | x | – | – | – | x | x | – | – | – | – | – | – | – |
| sp. E | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Trachyphyllia amaranthus* (Müller) | – | – | – | x | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – |
| *Hydnophora exesa* (Pallas) | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | – | x | – | – | – |
| sp. | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. | – | – | – | x | – | – | x | – | – | – | x | x | – | – | – | – | – | – | – | – | – | – |
| *Antillia constricta* Brüggemann var. *kiiensis* Y. and S. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *flabelliformis* Y. and S. | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *japonica* Y. and S. | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Fungia* cfr. *costulata* Ortmann. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *cyclolites* Lam. var. | x | x | – | x | x | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – |
| *fungites* (L.) var. *haimei* Verril | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *granulosa* Klunzinger | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *echinata* (Pallas) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *paumotensis* Stutchbury | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *rapanda* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| cfr. *scruposa* Klunzinger | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *scutaria* Lam. var. *danae* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | x |
| *scutaria* Lam. var. *placunaria* Klunz. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| *sinensis* M. Edw. and H. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *subrepanda* Döderlein | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *Herpetolitha limax* (Esper) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |

A=Riukiu; B=Taiwan; C=Ogasawara Group

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHÛ | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| *Döderleinia irregularis* Gardiner. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *Caulastrea aiharai* Y. and S., nov. sp. | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *conglobata* Y. and S., nov. sp. | – | – | – | x | x | – | – | x | x | – | x | – | – | – | – | – | – | – | – | – | – | – |
| *multiseptata* Y. and S. | – | – | – | x | x | – | – | – | – | – | x | – | – | – | – | x | – | – | – | – | – | – |
| *yokoyamai* Y. and S. | – | – | – | – | ? | – | – | – | – | – | x | – | – | – | x | – | – | – | – | – | – | – |
| *yokoyamai* var. *gracilis* Y. and S. | – | ? | – | x | – | – | – | – | x | – | – | – | – | x | – | – | x | – | – | – | x | x |
| *Mussa* cfr. *sinuosa* (Lam.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| cfr. *regalis* Dana | – | x | – | – | – | – | – | – | x | – | – | – | – | x | – | x | – | – | x | – | – | – |
| cfr. *tenuidentata* M.-Edw. and H. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| sp. A | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. B | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *Symphyllia* cfr. *acutus* Quelch | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| *nobilis* Dana | – | – | – | – | – | – | – | x | – | – | x | – | – | x | – | – | x | – | x | – | x | x |
| sp. nov. ? | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *Tridacophyllia laciniata* M.-Edw. and H. | – | – | – | x | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – | x | – | – |
| *laciniata* var. *japonica* Y. and S., nov. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| cfr. *paeonia* (Dana) | – | – | – | x | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – |
| *symphylloides* M.-Edw. and H. | – | ? | – | x | – | – | – | – | x | ? | x | – | – | – | x | – | – | – | – | – | – | – |
| *Acanthastrea* cfr. *echinata* Dana | – | – | – | – | – | – | – | x | x | – | x | – | – | x | – | x | – | – | – | – | – | x |
| *hemprichii* (Ehrenberg) | – | x | – | – | x | x | x | x | x | – | x | x | x | x | – | x | x | – | x | – | – | – |
| *Merulina ampliata* (Ellis and Sol.) | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | x | – | x | – | x | x |
| *laxa* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *Psammocora profundacella* Gardiner | – | x | – | x | x | – | – | x | – | – | x | – | – | – | – | – | – | – | – | – | – | – |
| *superficiales* Gardiner | – | x | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| cfr. *gonagra* Klunzinger | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| sp. | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – |
| *Agaricia ponderosa* Gardiner | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| *Pavona danai* M.-Edw. and H. | – | – | – | – | ? | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *decussata* Dana | – | x | – | x | x | – | – | x | – | – | x | – | x | x | – | – | x | – | x | ? | – | – |
| *decussata* Dana var. *minor* Y. and S., nov. | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | x | – | – |
| *divaricata* Lam. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *varians* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| cfr. *frondifera* Lam. | – | – | – | – | – | – | – | – | – | – | x | – | x | x | – | – | – | – | x | x | – | – |
| *Coscinarea columna* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| *monile* (Forskål) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – |
| *Podabacia crustacea* (Pallas) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *lobata* Van der Horst | – | ? | – | x | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – | – | – | – |
| *lobata* forma *kiiensis* Y. and S., nov. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – |
| *lobata* forma *numaensis* Y. and S., nov. | – | – | – | – | – | – | – | – | x | – | – | – | – | – | x | – | – | – | – | – | – | – |

A = Riukiu; B = Taiwan; C = Ogasawara Group

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHÛ | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| *lobata* forma *vanderhorsti* Y. and S., nov. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *lobata* var. *elegans* (Van der Horst) | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *lobata* var. *elegans* forma *pilicata* Y. and S., nov. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *lobata* var. *elegans* forma *setoensis* Y. and S., nov. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – |
| *lobata* var. *elegans* forma *variians* Y. and S., nov. | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *formosa* Y. and S., nov. sp. | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | x | – | – |
| *Coeloseris mayeri* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *Astraeopora* cfr. *gracilis* Bernard. | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | x | – | – | x | – | – | – |
| cfr. *incrustana* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *Turbinaria* cfr. *auricularis* Bernard | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *brüggemanni* Bernard | – | – | – | ? | – | – | – | – | – | – | x | – | – | – | – | – | – | x | – | – | – | – |
| *contorta* Bernard | x | – | – | x | x | x | x | x | x | – | x | x | x | x | x | x | x | – | x | – | – | – |
| *elegans* Bernard | – | – | – | x | – | – | – | – | x | – | – | – | – | x | – | – | x | – | x | – | x | x |
| *peltata* (Esper) | – | x | – | x | x | x | – | – | x | – | x | x | x | x | – | x | x | – | – | – | – | – |
| *sinensis* Verrill | – | – | – | ? | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – |
| *tubifera* Bernard | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | x | – | x | – |
| *undata* Bernard | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. | – | – | – | x | x | – | – | x | – | – | x | – | – | – | x | – | – | – | – | – | – | – |
| *Goniopora* sp. A | – | – | – | – | – | – | – | – | – | x | – | – | – | x | – | – | – | – | – | – | – | – |
| sp. B | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – |
| sp. C | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – | – |
| sp. D | – | x | – | – | x | – | – | x | x | – | – | – | – | x | – | x | – | – | – | – | – | – |
| sp. E | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| *Montipora cactus* Bernard | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *calcarea* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| *challengeri* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – | x |
| cfr. *effusa* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| cfr. *ehrenbergi* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| cfr. *elschneri* Vaughan | – | – | – | x | x | – | – | – | x | – | – | – | – | x | – | – | – | – | – | – | – | – |
| *foliosa* (Pallas) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x |
| *hispida* Dana | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | x | x | – |
| *informis* Bernard | – | – | – | – | – | – | – | – | x | – | x | – | – | – | – | – | – | – | x | – | x | x |
| *lanuginosa* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *levis* Quelch | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *patula* Verrill | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *pulcherima* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |
| *ramosa* Bernard (in the sense of Vaughan including *compressa*) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x |
| cfr. *squamosa* (Lam.) | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| nov. sp. ? | – | – | – | x | – | – | x | – | x | – | – | – | – | x | – | – | – | – | – | – | – | – |
| cfr. *venosa* (Ehr.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |

A = RIUKIU; B = TAIWAN; C = OGASAWARA GROUP

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHŪ | | | | | SHIKOKU | | | | | KIUSHŪ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ōsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ōshima Subgroup | Sharyōtō | Chichi-jima | Haha-jima |
| *verrilli* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | x | – |
| *verrilli* Vaughan var. *auaensis* Hoffm. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | x | x |
| *verrilli* Vaughan var. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *verrucosa* (Lam.) | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | x | – |
| sp. A | – | – | – | – | – | – | – | – | x | – | x | – | – | – | – | x | x | – | – | – | – | – |
| sp. B | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| *Acropora* (*Eumadrepora*) cfr. *abrotanoides* (Lam.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Eumadrepora*) *formosa* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Eumadrepora*) *formosa* (Dana) var. *gracilis* (Dana)? | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Eumadrepora*) *formosa* var. *brachiata* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | – |
| (*Eumadrepora*) *gravida* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | – |
| (*Eumadrepora*) *haimei* (M.-Edw. a ‹ H.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | x | – |
| (*Eumadrepora*) cfr. *muricata* L. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Eumadrepora*) *muricata* L. forma *plamata* Lam. | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – |
| (*Eumadrepora*) cfr. *smithi* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| (*Eumadrepora*) *tutuilensis* Hoffmeister | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| (*Isopora*) *nobilis* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| (*Isopora*) *palifera* (Lam.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Lepidocyathus*) *hehes* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – | – |
| (*Lepidocyathus*) *squamosa* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Lepidocyathus*) cfr. *studeri* (Brook) | x | – | – | x | x | x | x | – | x | – | x | – | x | x | – | x | x | – | – | – | – | – |
| (*Lepidocyathus*) *sublata* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Polystachys*) cfr. *anthocervis* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Polystachys*) *cerealis* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| (*Polystachys*) cfr. *conferta* (Quelch) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Polystachys*) cfr. *hyacinthus* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | x | – |
| (*Polystachys*) cfr. *latistella* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| (*Polystachys*) cfr. *pectinata* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| (*Polystachys*) cfr. *quelchi* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |

A = Riukiu; B = Taiwan; C = Ogasawara Group

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHÛ | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| (*Polystachys*) cfr. *quelchi* (Brook) var. *paradoxa* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Polystachys*) *sinensis* (Brook) | – | – | – | – | x | – | – | – | x | – | – | – | – | – | – | – | – | – | – | x | – | – |
| (*Rhabdocyathus*) *hemprichi* (Ehr.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Rhabdocyathus*) cfr. *hemprichi* (Ehr.) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Rhabdocyathus*) *squarrosa* (Ehr.) | – | x | – | x | x | x | – | – | – | – | x | – | – | x | – | x | x | – | – | – | – | – |
| (*Rhabdocyathus*) *valida* (Dana) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | x |
| (*Rhabdocyathus*) *variabilis* (Klunz.) | – | – | – | – | ? | – | – | – | – | – | x | – | – | – | – | – | – | x | – | x | x | – |
| (*Rhabdocyathus*) sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| (*Tylopora*) *gemmifera* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| (*Tylopora*) *leptocyathus* (Brook) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x | – | x | – |
| (*Tylopora*) cfr. *pagoensis* Hoffmeister | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – |
| (*Tylopora*) *scherizeriana* (Brüggemann) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| sp. A | – | – | – | x | x | x | – | – | x | – | x | – | x | x | – | x | – | – | – | – | – | x |
| sp. B | – | – | – | – | x | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – |
| sp. C | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. D | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. E | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | x | – | – |
| sp. F | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| sp. G | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – |
| *Porites andrewsi* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| cfr. *australiensis* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – |
| cfr. *ceylonica duodecima* Bernard | – | x | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – |
| *compressa* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *compressa* Dana forma *abacus* Vaughan | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | x | – | x | – | – | – | – |
| cfr. *compressa* forma *fragilis* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *convexa* (Verrill) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| cfr. *haddoni* Vaughan | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *lanuginosa* Studer | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *latistellata* Quelch var. ? | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *lichen* Dana | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| cfr. *lobata* Dana forma *centralis* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| cfr. *lobata* Dana forma *centralis* subforma *alpha* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | – |

A = Riukiu; B = Taiwan; C = Ogasawara Group

TABLE IV. (*Continued*)

| SPECIES \ LOCALITIES | HONSHU | | | | | SHIKOKU | | | | | KIUSHÛ | | | | | | | A | | B | C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tateyama-wan | Enoura-wan | Yura-wan | Tanabe-wan | Kushimoto | Muroto-saki | Tei | Susaki | Misaki | Uwajima-wan | Hiuga coast | Ôsumi coast | Kagoshima-wan | So. coast of Satsuma | Hizen coast | Amakusa | Koshiki-jima | Sakishima Subgroup | Ôshima Subgroup | Sharyôtô | Chichi-jima | Haha-jima |
| cfr. *lobata* Dana *centralis* subforma *epsilon* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| cfr. *lutea* M.-Edw. and H. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| cfr. *murrayensis* Vaughan | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *nigrescens* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | – | – | – |
| cfr. *purpurea* Gardiner | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – |
| cfr. *quelchi* Studer | – | – | – | x | – | – | x | x | – | x | x | x | – | – | – | – | – | – | – | – | – | – |
| *salomonis* quarta Bernard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |
| *schauinslandi* Studer | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *sinensis noma* Bernard ? | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – |
| *singaporensis quinta* Bernard | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – | – |
| cfr. *somaliensis* Gravier | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | x | x |
| *tenuis* Verrill | – | – | – | – | x | – | – | – | – | – | – | – | x | – | – | – | – | x | – | x | x | x |
| sp. A | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – |
| sp. B | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. C | – | – | – | – | – | – | – | – | – | x | – | – | – | – | – | – | – | – | – | – | – | – |
| sp. D | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| sp. E | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x |
| *Alveopora* cfr. *verrilliana* Dana | – | – | – | x | – | – | – | – | – | – | x | – | – | – | – | x | – | – | – | – | x | x |
| *Heliopora coerulea* (Pallas) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x | x | – | – |
| *Tubipora musica* L. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| *Millepora* cfr. *platyphyllia* Ehr. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – |
| *tortuosa* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | ? | x | – | – |
| *truncata* Dana | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | x |
| sp. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | x | – | – | – | – |

A=Riukiu; B=Taiwan; C=Ogasawara Group

tends up to the shallower sea floor, where they are exposed at the low neap tide. As to how deep the coral growth extends along these coasts, we have at present no information. Certain corals seem to be markedly tolerant of mud. For instance, several species of *Podabacia*, *Favia*, *Cyphastrea*, *Hydnophora*, and *Acropora* are living in calm water inside the Tanabe-wan, where influx of muddy water from land is frequent (Text-Fig. 3).

The northernmost localities of reef corals are in Tateyama-wan, lat. 35°10′ N., long. 139°50′ E., and Enoura-wan, lat. 35°05′ N., long. 138°12′ E. The monthly temperature and specific gravity of the sea water at Tateyama, on Tateyama-wan, in 1921 and those at Seto, on Tanabe-wan, in 1929 are as shown on page 207.

The Riukiu Islands, Ogasawara Islands and Taiwan have coral reefs, fringing reefs or bank barriers, where the conditions for growth are favorable.

*Monthly Temperature and Specific Gravity of Sea Water at Tateyama and Seto*

| Tateyama, Tateyama-wan | | | Seto, Tanabe-wan | | |
|---|---|---|---|---|---|
| 1921 | Temp. C° | Sp. Gr. | 1929 | Temp. C° | Sp. Gr. |
| 1 | 13.0 | 24.95 | 1 | 12.1 | 25.5 |
| 2 | 12.1 | 25.39 | 2 | 15.3 | 25.8 |
| 3 | 13.5 | 25.22 | 3 | 16.6 | 25.5 |
| 4 | 14.8 | 24.70 | 4 | 18.8 | 24.5 |
| 5 | 18.1 | 24.82 | 5 | 22.1 | 23.3 |
| 6 | 19.6 | 24.79 | 6 | 23.5 | 22.4 |
| 7 | 23.2 | 25.26 | 7 | 26.8 | 21.5 |
| 8 | 24.2 | 24.70 | 8 | 27.7 | 20.3 |
| 9 | 23.6 | 23.76 | 9 | 27.0 | 20.1 |
| 10 | 20.8 | 23.96 | 10 | 23.0 | 21.6 |
| 11 | 17.0 | 25.37 | 11 | 21.3 | 23.0 |
| 12 | 14.2 | 24.90 | 12 | 15.0 | 23.4 |

S. Hanzawa, of our Geological Institute, who visited several times the Riukiu Islands for geological study gave us the following information about the coral reefs of Okinawa-jima and the islands of the Sakishima subgroup (Miyako-jima, Ishigaki-jima, Yonaguni-jima, Iriomote-jima), where he had opportunities to make observations on these structures.

Coral reefs along the coasts of these islands are fringing reefs; some of them may better be called bank barriers. They vary in breadth even about the same island—for instance, having a breadth of 2000 to 2500 m. along the northeastern coast of Iriomote-jima and of 250 to 1500 m. along its southwestern coast; 1000 to 1600 m. along the eastern coast of Ishigaki-jima and 200 (or less) to 900 m. along its western coast.

Around Okinawa-jima fringing reefs are well developed, broadest near Itoman and near Naha, where they are 4000 and 3000 m. broad, respectively, though at certain places they are reduced to a narrow belt of hardly 150 m. width. Northeast of Guschichan, coral reefs occupy a narrow off-shore belt some 4000 m. from shore, within which the water has an average depth of 2 m. and a maximum depth of 9 m.

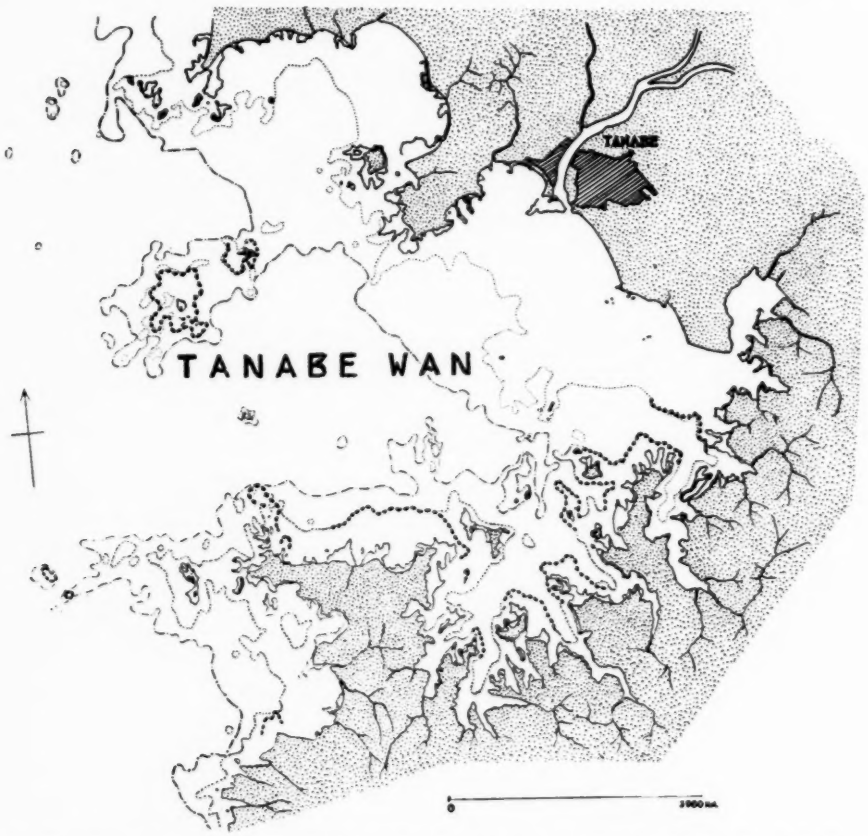
The breadth of the coral reefs around Okinawa-jima seems to depend on various factors. Among them two factors are believed to be especially important: (1) the breadth of the higher submarine terraces,[31] with their outer boundary slope descending steeply from 40 m. to 80 m., or occasionally from 30 m. to 60 m.; (2) the rate of the latest land submergence. The island being divided into many geological blocks by dislocations younger than the building of the submarine terraces, the coral reefs built or being built on the higher terraces are very variable in breadth from place to place.

The fringing reefs of Okinawa-jima as well as the islands of the Sakishima subgroup have the so-called boat channel inside the outer rim, which is slightly exposed above

[31] The island is surrounded by terraces of 2 different depths; the lower terraces are limited seaward by the steep slope between 100 m. and 140 m.

sea level at low water as dark brown bars several meters broad running subparallel to the shore. At low water the boat channels are transformed almost to lagoons. The bottom of these boat channels, or reef flats lying beneath a thin sheet of sea water, is usually covered by foraminiferal sands over a considerable area, and is often quite free from living coral stocks. At places it is covered by dense groves of staghorn-shaped stocks of *Acropora*, or at other places with massive heads of *Favia*, *Favites*, *Goniastrea*, *Porites*, etc., in groups.

The reefs are traversed more or less radially by many passages and numerous furrows. The latter are narrower and shorter than the passages and of a quite different nature, being deep transverse clefts extending from the reef-margin and only in narrow reefs reaching near to the shore. The furrows are narrow, 1 m. or less to 2 or 3 m. broad, and are bordered by steep or even overhanging side-walls.

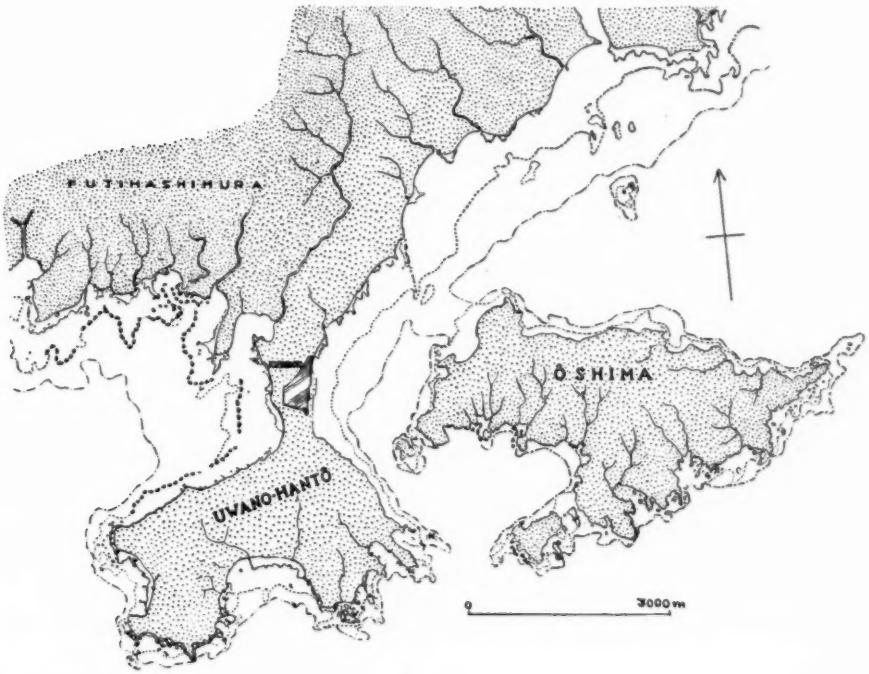



TEXT-FIG. 3—Tanabe-wan: distribution of reef corals; dotted line, 10 m. depth; chain line, 20 m. depth; heavy broken line, outer margin of reef area.

Some of the passages were antecedent to the building of coral reefs, possibly being drowned valleys, though other passages, as well as all the furrows, have no relation to the drowned valleys.

The furrows are sometimes interpreted as a product of erosion by streamlets of sea water dashing on and withdrawing from the surface of the reefs, but Hanzawa looks on them rather as chasms left between the lateral borders of lobes into which the growing outer margins of the reefs are divided. In this explanation the furrows on the reef surface from their heads outwards gradually become shallower and are finally abolished by growing organisms, instead of being gradually enlarged by erosion. Reef corals enjoy luxuriant growth along and near the margin of reefs and in the furrows.

The mean monthly temperature and specific gravity of sea water at Ishigaki-jima, Sakishima subgroup, is as shown on page 210.




TEXT-FIG. 4—Kushimoto: distribution of reef corals; dotted line, 10 m. depth; chain line 20 m. depth; heavy broken line outer margin of reef area.

On the other hand, the more northerly islands—Kiushû, Shikoku and Honshû—have no well developed coral reefs, although reef building corals thrive along the Pacific coasts of Shikoku and Honshû and along the Pacific as well as Genkai-

*Monthly Temperature and Specific Gravity of Sea Water at Ishigaki-jima*

| 1931 | Temp. C° | Sp. Gr. |
|---|---|---|
| 1 | 19.4 | 24.98 |
| 2 | 21.2 | 25.18 |
| 3 | 20.7 | 25.18 |
| 4 | 22.7 | 25.50 |
| 5 | 26.1 | 25.12 |
| 6 | 27.5 | 25.00 |
| 7 | 28.8 | 24.85 |
| 8 | 28.8 | 24.83 |
| 9 | 28.5 | 23.86 |
| 10 | 25.9 | 24.45 |
| 11 | 24.0 | 25.03 |
| 12 | 21.4 | 25.31 |

nada coasts of Kiushû under the influence of the warm-water current, Kuroshiwo, from the south, and its branches. The northernmost points on the Japanese coasts where the coral growth is more or less vigorous are Enoura, on Suruga-wan, and Tateyama-wan of the Sagami-nada, in lat. 35°10′ N.

The Ogasawara (Bonin) group is situated some 15° of longitude east of Okinawa-jima. Sugiyama made the following observation about the coral growth along the coasts of Chichi-jima and Haha-jima, the two largest islands of the group.

Reef corals are not flourishing along the east coast of the islands, which is directly exposed to strong winds and violent oceanic waves, owing to the rapid descent of the sea bottom off shore. They seem to prefer the more sheltered places in these islands, as their growth is most vigorous, for instance, in Futami-wan, Miyanohama, Tsurihama, and Susaki on Chichi-jima, and the coast of Okimura, Nishiura and Nankinhama on Haha-jima.

Futami-wan, of Chichi-jima (Text-Fig. 5), almost the only harbour of the island group, is an inlet open to the west. Its dimensions are 2 km. east-west and 1.5 km. north-south, apart from a northeastern extension 1.5 km. long. The water is shallow, some 80 m. at the deepest (middle) part. It is deeper along the line diametrically traversing the bay from the head of its northeastern section southwestwards.

North-east and south-west gales prevail, but at no time is the water of the northeastern section of the bay much disturbed. This part is well

TEXT-FIG. 5—Futami-wan, Chichi-jima; distribution of reef corals; arrows show currents; heavy broken line, outer margin of reef area.

sheltered from the wind and is the only place where reef corals are luxuriant.

Reef corals, especially branching *Acropora haimei* (M.-Edw. and H.)

and *A. formosa* (Dana) var., thrive in the northeastern section of the bay to a depth of about 25 m. and there a kind of fringing reef has been built. The coral reef is 150 m. broad along the coast of Byôbudani and Ômura and has grown to a lobe prolonged southwestwards just over the deep median part between the 2 coasts; the lobe is 800 m. long and 1.5 m. high at its distal, outgrowing edge. In front of it the sea bottom is muddy.

Fifteen meters is an estimated thickness of the coral reef, estimated on the mean slope of the sea bottom off shore at this place; a well dug through the sandy plain of the coast of Byôbudani passed through a reef rock 12 m. thick and from this the above estimation is verified.

Along the western half of the coast of Ômura the coral growth is less vigorous, the sea bottom being overgrown by numerous stocks but with their interspaces left bare. The coral fauna is, however, more varied in this part than in the reef within the northeastern section. In the latter we see an extensive grove of branching *Acropora haimei* covering the entire surface of the reef, while in the former, *Montipora*, several species, and *Pocillopora*, especially *Pocillopora maeandrina*, are most abundant among many other corals. *Millepora* and *Porites* like more agitated water and are common along the outer margin of the belt of growing corals; the former is especially flourishing at Sakaura on the eastern coast of the bay.

Miyanohama is rich in *Tubipora musica*. The coral fauna of this place is much like that of the coast of Oki-mura in Haha-jima. *Fungia* is also common in both places.

Coral growth is not so luxuriant along the coast of Nankinhama and Oki-mura, Haha-jima, as to cover the entire surface of the sea bottom, the foundation being always more or less exposed between the coral stocks.

Coral growth in the Ogasawara Group differs essentially from that along the coasts of Kiushû, Shikoku and Honshû in that corals are living in shallower waters and their stocks

*Monthly Temperature and Specific Gravity of Sea Water at Kanameiwa*

Kanameiwa, Futami-wan
April, 1930 to March, 1931

| | Surface | | −10 m. | | −25 m. | |
|---|---|---|---|---|---|---|
| | Temp. C° | Sp. Gr. | Temp. C° | Sp. Gr. | Temp. C° | Sp. Gr. |
| 1 | 21.5 | 25.29 | 21.3 | 25.46 | 21.2 | 25.58 |
| 2 | 21.5 | 25.16 | 21.2 | 25.00 | 21.2 | 24.82 |
| 3 | 21.2 | 25.35 | 21.3 | 25.33 | 20.9 | 25.35 |
| 4 | 21.3 | 25.85 | 20.9 | 25.89 | 20.6 | 26.16 |
| 5 | 23.9 | 26.00 | 23.5 | 26.01 | 23.3 | 26.18 |
| 6 | 25.5 | 26.37 | 24.6 | 26.15 | 24.6 | 26.25 |
| 7 | 26.4 | 25.98 | 24.8 | 26.07 | 23.5 | 26.19 |
| 8 | 24.9 | 25.31 | 23.8 | 25.32 | 23.9 | 25.35 |
| 9 | 26.2 | 25.95 | 25.9 | 25.82 | 25.0 | 25.98 |
| 10 | 25.9 | 25.54 | 25.6 | 25.73 | 25.0 | 25.71 |
| 11 | 24.3 | 25.14 | 24.1 | 25.57 | 23.3 | 25.43 |
| 12 | 22.2 | 25.63 | 22.2 | 25.58 | 21.8 | 25.61 |

are exposed above the water at neap tides (Pl. 21).

The mean temperature and specific gravity of water at Kanameiwa on Futami-wan is as follows:

Some 2000 samples of reef coral stocks have been collected from Taiwan, the Riukiu Islands, the Ogasawara Islands, Kiushû, Shikoku and Honshû, and 249 species, including varieties and formae, in 44 genera were provisionally discriminated among them, as follows:

*Reef Corals from Taiwan, Riukiu Islands, Ogasawara Islands, Kiushû, Shikoku and Honshû.*

*Stylophora*, 4 sp.
*Seriatopora*, 2 sp.
*Euphyllia*, 2 sp.
*Cyphastrea*, 5 sp., 1 var.
*Stylocoenia*, 1 sp.
*Leptastrea*, 1 sp.
*Echinopora*, 1 sp.
*Echinophyllia*, 3 sp.
*Orbicella*, 5 sp.
*Favia*, 6 sp.
*Favites*, 3 sp.
*Goniastrea*, 6 sp.
*Leptoria*, 3 sp.
*Maeandra*, 10 sp.
*Trachyphyllia*, 1 sp.
*Hydnophora*, 3 sp.
*Antillia*, 3 sp.
*Fungia*, 13 sp.
*Herpetolitha*, 1 sp.
*Döderleinia*, 1 sp.
*Caulastraea*, 4 sp., 1 var.
*Mussa*, 5 sp.
*Symphyllia*, 3 sp.
*Tridacophyllia*, 3 sp., 1 var.
*Pocillopora*, 7 sp., 1 var.
*Galaxea*, 2 sp.
*Acanthastrea*, 2 sp.
*Merulina*, 2 sp.
*Psammocora*, 5 sp.
*Agaricia*, 1 sp.
*Pavona*, 5 sp., 1 var.
*Coscinarea*, 2 sp.
*Podabacia*, 3 sp., 7 var. and forma
*Coeloseris*, 1 sp.
*Astraeopora*, 2 sp.
*Turbinaria*, 9 sp.
*Goniopora*, 5 sp.
*Montipora*, 23 sp., and var.
*Acropora*, 42 sp., var. and forma
*Porites*, 30 sp., var. and forma
*Alveopora*, 1 sp.
*Heliopora*, 1 sp.
*Tubipora*, 1 sp.
*Millepora*, 4 sp.

Our reef coral fauna is exceedingly varied, contrary to our expectation, as is evident in a comparison with the fauna of the Philippine seas, where coral reefs of varied types are well developed. From this region Faustino[32] enumerated 154 well established species and varieties in 40 genera; in detail he had:

*Reef Corals from the Philippine Seas*

*Stylophora*, 4 sp.
*Seriatopora*, 8 sp., 1 var.
*Pocillopora*, 4 sp.
*Euphyllia*, 1 sp.
*Cyphastrea*, 4 sp.
*Leptastrea*, 2 sp.
*Echinopora*, 2 sp.
*Galaxea*, 3 sp.
*Favia*, 4 sp.
*Favites*, 4 sp.
*Goniastrea*, 3 sp.
*Leptoria*, 2 sp.
*Maeandra*, 4 sp.
*Trachyphyllia*, 1 sp.
*Hydnophora*, 3 sp.
*Antillia*, 1 sp.
*Mussa*, 4 sp.
*Symphyllia*, 1 sp.
*Pectinia* (=*Tridacophyllia*), 4 sp.
*Acanthastrea*, 1 sp.
*Merulina*, 4 sp.
*Fungia*, 16 sp., 2 var.
*Halomitra*, 4 sp.
*Herpetolitha*, 1 sp.
*Polyphyllia*, 1 sp.
*Agaricia*, 1 sp.
*Pachyseris*, 1 sp.
*Pavona*, 3 sp.
*Podabacia*, 1 sp.
*Haloseris* 1 sp.
*Leptoseris*, 1 sp.
*Coeloseris*, 1 sp.
*Aulastraea*, 1 sp.
*Turbinaria*, 1 sp.
*Montipora*, 6 ap.
*Acropora*, 29 sp., 1 var.
*Goniopora*, 5 sp.
*Porites*, 9 sp.
*Heliopora*, 1 sp.
*Millepora*, 3 sp.

In his papers Faustino made no mention of *Caulastraea*, *Orbicella*, *Echinophyllia*, and *Astraeopora*, which are well represented in the Japanese seas. The Philippine seas also seem to be characterised by the paucity of species of *Turbinaria*, *Podabacia* and *Antillia*, which are common in the Japanese seas.

In the Atlantic Ocean reef corals enjoy vigorous growth 1 to 3 ft. below tide around the Bermuda Islands, lying in lat. 32°15′ to 32°23′ N. and hence approximately in the same latitude as Hosojima, on the coast of Hiuga (Kiushû). The islands are situated amid the Gulf stream, and the

[32] Faustino, L. A., Coral reefs of the Philippine Islands: *Philippine Jour. Sci.*, vol. 44, no. 3, pp. 291–305, 1931; *Recent Madreporaria of the Philippine Islands*, 1927.

EXPLANATION OF PLATE 21—*Acropora haimei* grove exposed at low tide, Ô-mura, Futami-wan (northwestern coast), Chichi-jima.

Yabe and Sugiyama, Reef Corals

temperature of the surface sea water is higher than in the southern part of Kiushû.

*Mean Monthly Surface Temperature of Sea Water (after Verrill)*[33]

| | |
|---|---|
| January | 15° –17°.2 |
| February | 15° –17°.2 |
| March | 16°.6–18°.8 |
| April | 18°.8–21°.6 |
| May | 21°.1–24°.4 |
| June | 23°.8–26°.6 |
| July | 26°.1–28°.3 |
| August | 27°.7–29°.4 |
| September | 18°.3–23°.8 |
| October | 23°.8–20°.5 |
| November | 20°.5–18°.3 |
| December | 18°.3–16°.1 |

Coral reefs which are sometimes called pseudatolls cover an extensive area between 32°30′ to 32°12′, and mark the northern limit of the typical coral reefs in the Atlantic.

The reef coral fauna of Bermuda is remarkably poor in the number of genera and species represented. Verrill once distinguished in the shallow water around the islands 22 species and varieties of corals, which belong to the following 10 genera: *Maeandra* (2 species), *Favia* (1), *Mussa* (including *Isophyllia*) (5), *Orbicella* (1), *Stephanocoenia* (1), *Oculina* (4 and 1 variety), *Madracis* (1), *Porites* (2), *Siderastrea* (2), and *Agaricia* (1). In addition there is a species of *Millepora*.

It is stated that the reef coral fauna of Bermuda was probably derived from that of the West Indies in post-Pleistocene time. There is an essential and striking difference between the two faunas, namely, the total absence in Bermuda of corals belonging to the genera *Cyphastrea* and *Acropora*. A similar difference in the constitution of reef coral faunas exists between the Hawaiian Islands and the Philippines-East Indies.

We are well informed concerning the reef-building coral fauna of the Hawaiian Islands through the elaborate work of T. W. Vaughan.[34] According to him, there are 86 species and varieties in 16 genera. The dominant types of coral found there are *Pocillopora*, *Porites*, and *Montipora*, which are well represented in the number of species and abundant in the number of individuals. On the other hand, the absence or rarity of *Acropora*, *Orbicellidae*, *Favidae*, and *Mussiidae* is worthy of special notice. These genera being represented by a number of species in the Japanese seas, their absence or rarity in the Hawaiian seas can not be attributed solely to the lower temperature of sea water as compared to that of the more southern or southwestern tropical coral seas. This fact is considered by us as evidence rather favorable to the explanation suggested by Vaughan for the absence or rarity of *Acropora* in the Hawaiian Islands in the middle of the Pacific, as well as in the Bermuda Islands in the middle of the Atlantic. Each of them lies some distance from the chief areas of reef corals in its own region.

A. G. Mayor and C. Crossland[35]

[33] Verrill, A. E., The Bermuda Islands: *Conn. Acad. Arts Sci., Trans.*, vol. 11, part 2, p. 503, 1901–1902.

[34] Vaughan, T. W., *Recent Madreporaria of the Hawaiian Islands and Laysan*, 1907. Temperature of the surface sea water in the Hawaiian seas is February, 23° to 24°; May, 24°; August, 25°; November, 25°. Daly, R. A., The glacial-control theory of coral reefs: *Am. Acad. Arts Sci., Proc.*, vol. 51, no. 4, p. 168. 1915.

[35] Crossland, C., Notes on the ecology of the reef-builders of Tahiti: *Zool. Soc. London, Proc.*, (1928), part 2, p. 718.

*Composition of Japanese Reef Coral Faunas*

| Genera | Number of species in each genus | Northern | | Riukiu | Ogasawara |
|---|---|---|---|---|---|
| | | Honshû and Shikoku | Kiushû | | |
| *Stylophora* | 4 | 3 | 1 | 1 | 0 |
| *Seriatopora* | 2 | 0 | 0 | 2 | 0 |
| *Pocillopora* | 8 | 1 | 1 | 5 | 5 |
| *Galaxea* | 2 | 0 | 0 | 2 | 2 |
| *Euphyllia* | 2 | 2 | 1 | 2 | 1 |
| *Cyphastrea* | 6 | 5 | 3 | 2 | 3 |
| *Stylocoenia* | 1 | 1 | 0 | 0 | 0 |
| *Leptastrea* | 1 | 1 | 1 | 0 | 1 |
| *Echinopora* | 1 | 0 | 0 | 0 | 1 |
| *Echinophyllia* | 3 | 2 | 1 | 1 | 1 |
| *Orbicella* | 5 | 4 | 4 | 1 | 1 |
| *Favia* | 6 | 5 | 3 | 3 | 5 |
| *Favites* | 3 | 3 | 3 | 1 | 0 |
| *Goniastrea* | 6 | 3 | 4 | 5 | 2 |
| *Leptoria* | 3 | 0 | 0 | 3 | 2 |
| *Maeandra* | 10 | 9 | 7 | 3 | 4 |
| *Trachyphyllia* | 1 | 1 | 0 | 0 | 0 |
| *Hydnophora* | 3 | 3 | 2 | 1 | 0 |
| *Antillia* | 3 | 3 | 0 | 0 | 0 |
| *Fungia* | 13 | 1 | 2 | 10 | 2 |
| *Herpetolitha* | 1 | 0 | 0 | 1 | 0 |
| *Döderleinia* | 1 | 0 | 0 | 1 | 0 |
| *Caulastrea* | 5 | 5 | 4 | 0 | 1 |
| *Mussa* | 5 | 2 | 1 | 1 | 3 |
| *Symphyllia* | 3 | 1 | 1 | 2 | 1 |
| *Tridacophyllia* | 4 | 4 | 3 | 0 | 0 |
| *Acanthastrea* | 2 | 2 | 2 | 1 | 1 |
| *Merulina* | 2 | 0 | 1 | 2 | 1 |
| *Psammocora* | 5 | 2 | 3 | 0 | 1 |
| *Agaricia* | 1 | 0 | 0 | 0 | 1 |
| *Pavona* | 6 | 2 | 3 | 2 | 2 |
| *Coscinarea* | 2 | 0 | 1 | 0 | 1 |
| *Podabacia* | 10 | 7 | 5 | 1 | 0 |
| *Coeloseris* | 1 | 0 | 0 | 1 | 0 |
| *Astraeopora* | 2 | 1 | 1 | 1 | 1 |
| *Turbinaria* | 9 | 8 | 7 | 4 | 2 |
| *Goniopora* | 5 | 2 | 3 | 1 | 0 |
| *Montipora* | 23 | 8 | 6 | 10 | 16 |
| *Acropora* | 42 | 8 | 6 | 22 | 20 |
| *Porites* | 30 | 7 | 8 | 17 | 9 |
| *Alveopora* | 1 | 1 | 1 | 0 | 1 |
| *Heliopora* | 1 | 0 | 0 | 1 | 0 |
| *Tubipora* | 1 | 0 | 0 | 0 | 1 |
| *Millepora* | 4 | 0 | 0 | 2 | 2 |
| Total No. of Species | 249 | 105 | 92 | 112 | 94 |
| Total No. of Genera | 44 | 31 | 29 | 33 | 30 |

have shown that the coral fauna becomes gradually poorer eastwards in the southwestern Pacific. The former author estimated that of Samoa at only two-thirds of that of northern Australia, and the latter found 11 genera present in Samoa which are absent in Tahiti.

Crossland listed the following 16 genera absent from Tahiti, of which those marked F are recorded from Fiji (or Rotuma) and those marked S from Samoa:

| | | | |
|---|---|---|---|
| *Seriatopora* | F | *Goniastrea* | FS |
| *Acrohelia* | F | *Leptoria* | FS |
| *Euphyllia* | FS | *Maeandra*, i.e. *Coeloria* | FS |
| *Echinophora* | F | *Hydnophora* | FS |
| *Galaxea* | FS | *Symphyllia* | FS |
| *Favites* | FS | *Merulina* | S |
| *Diploastrea* | FS | *Turbinaria* | F |
| *Astraeopora* | FS | *Goniopora* | |

Furthermore, it is stated that *Heliopora* and *Tubipora* are also lacking in Tahiti, and 5 genera, *Lobophyllia* (*Mussa*), *Stylophora*, *Favia*, *Cyphastrea* and *Pachyseris* are in process of disappearance.

Our Japanese reef coral fauna is geographically separable into three sub-faunas, the Ogasawara, the Riukiu, and the northern (Honshû, Shikoku and Kiushû) subfauna. Taiwan is for the present excluded from consideration, as the material now available is very scanty and is from the northernmost part only. From the geographical position of the island, however, it may not be misleading to assume that its coral fauna is intermediate in composition between that of the Philippines and that of the Riukiu.

The number of genera and species of corals constituting the subfaunas are shown on preceding page.

The number of genera common to each pair of these subfaunas is:

*Reef Coral Genera Common to Subfaunas*

| | N. | | R. | O. |
|---|---|---|---|---|
| | H.-S. | K. | | |
| H.-S. | 31 | 28 | 22 | 22 |
| K. | 28 | 29 | 24 | 25 |
| R. | 22 | 24 | 33 | 22 |
| O. | 22 | 25 | 22 | 30 |

The number of species common to each pair of these subfaunas is:

*Reef Coral Species Common to Subfaunas*

| | N. | | R. | O. |
|---|---|---|---|---|
| | H.-S. | K. | | |
| H.-S. | 105 | 63 | 24 | 27 |
| K. | 63 | 92 | 32 | 29 |
| R. | 24 | 27 | 112 | 35 |
| O. | 27 | 29 | 35 | 94 |

Gradual reduction of reef corals in number of species and genera is expected in passing from the central area of coral growth in the tropical regions toward the northern and southern seas of the temperate regions, as physical conditions adverse to the life of reef corals gradually appear. Superficially just the reverse is, however, shown by the above list of genera, the number of species being inferior in the Riukiu and Ogasawara subfauna to that in the northern subfauna. This is, we believe, partly ascribable to the following circumstances:

(1) *Podabacia* and *Caulastraea* living along the coasts of Honshû and Shikoku are very variable, and they have contributed much toward multiplying the number of species, varieties, and formae.

(2) Where reef-corals are most prosperous and the dominant types are found in overwhelming number of individuals, the collecting of less numerous elements is a task of greater difficulty than at places where corals are less flourishing.

Nevertheless, it is marvellous that 105 species, in 31 genera, are found along the coasts of Honshû and Shikoku, and the conclusion seems inevitable that the reduction of genera and species in passing from the tropical Pacific to our latitudes is but slight.

The three subfaunas of the Japanese reef corals, in comparison with one another, show interesting differences.

The northern subfauna has the following characteristics: (1) Absence of *Tubipora*, *Millepora*, *Heliopora*, *Galaxea*, *Coeloseris*, *Echinopora*, *Seriatopora*, *Leptoria*, and *Agaricia;* (2) relative rarity of *Mussa*, *Symphyllia*, *Pocillopora*, and *Porites*, and great rarity of *Fungia;* (3) abundance of *Hydnophora* and *Turbinaria*, and richness in varieties of *Caulastraea* and *Podabacia*.

The characteristic aspect of the Riukiu subfauna consists in (1) the absence(?) of *Tubipora*, and the absence or rarity of *Hydnophora*, *Antillia*, and *Podabacia;* (2) presence of *Heliopora*, *Millepora*, *Seriatopora*, *Galaxea*, and *Leptoria;* (3) great abundance of *Fungia*, *Acropora*, *Montipora*, and *Porites*.

The Ogasawara subfauna is distinguished by (1) the absence(?) or great rarity of *Heliopora*, *Seriatopora*, *Hydnophora*, *Antillia*, and *Podabacia*, and rarity of *Turbinaria;* (2) presence of *Echinopora* and *Agaricia*, the presence in profusion of *Tubipora*, *Millepora*, *Mussa*, *Symphyllia*, *Fungia*, *Pocillopora*, and *Porites*, and the great abundance of *Montipora;* (3) abundance in number of individuals of *Acropora haimei* and *Acropora formosa* (Dana) var., as compared with other species of the same genus.

In regard to the reduction of genera from west to east in the southwestern Pacific, mentioned above, it is interesting to note that corals of the genera *Seriatopora*, *Coeloseris*, *Galaxea*, *Millepora*, *Leptoria*, and *Heliopora*, which are common in the coral reefs of the Riukiu Islands, Taiwan, and the Ogasawara Islands, do not occur in the present collection from Kiushû, Shikoku, and Honshû; and also that other genera are represented in the latter areas by fewer species than in the former areas, namely, 1 out of 7 species and varieties of *Pocillopora*, 2 out of 13 species of *Fungia*, 8 out of 22 species and varieties of *Montipora*, 8 out of 42 species and varieties of *Acropora*, and 12 out of 30 species and varieties of *Porites*.

In the following list are enumerated the species of reef corals living in the Enoura-wan and Tateyama-wan, the northernmost localities

*Reef Corals Living in the Enoura-wan and Tateyama-wan*

| | Tateyama-wan | Enoura-wan |
|---|---|---|
| *Stylophora* cfr. *danae* M.-Edw. and H. | — | c |
| *Stylophora* sp. nov.? | — | x |
| *Cyphastrea chalcidicum* Klunzinger | — | c |
| *Cyphastrea serailia* (Forskål) | — | c |
| *Stylocoenia japonica* Yabe and Sugiyama | — | x |
| *Leptastrea purpurea* (Dana) | x | x |
| *Echinophyllia* sp. (A) | — | c |
| *Echinophyllia?* sp. (B) | — | x |
| *Favia* cfr. *amplior* (M.-Edwards and Haime) | — | x |
| *Favia* cfr. *matthai* Vaughan | — | x |
| *Favia pallida* (Dana) | — | x |
| *Favia speciosa* (Dana) | — | c |
| *Favites* cfr. *abdita* (Ellis and Soll.) | — | x |
| *Goniastrea pectinata* (Ehrenberg) | x | x |
| *Maeandra lamellina* Ehrenberg | — | x |
| *Maeandra* sp. (A) | — | c |
| *Maeandra* sp. (B) | — | x |
| *Hydnophora exesa* (Pallas) | c | x |
| *Hydnophora* sp. | x | — |
| *Antillia japonica* Yabe and Sugiyama | — | x |
| *Fungia cyclolites* Lam. var. | x | x |
| *Caulastraea aiharai* Yabe and Sugiyama, sp. nov. | — | x |
| *Caulastraea yokoyamai* var. *gracilis* Yabe and Sugiyama | — | x |
| *Mussa* cfr. *regalis* Dana | — | x |
| *Tridacophyllia* cfr. *symphylloides* M.-Edw. and H. | — | x |
| *Acanthastrea hemprichii* (Ehrenberg) | — | x |
| *Psammocora profundacella* Gardiner | — | x |
| *Psammocora sabigniensis* Gardiner | — | x |
| *Pavona decussata* Dana | — | x |
| *Podabacia lobata* Van der Horst (?) | — | x |
| *Turbinaria contorta* Bernard | c | — |
| *Turbinaria peltata* (Esper) | — | x |
| *Goniopora* sp. | — | x |
| *Acropora squarrosa* (Ehernberg) | — | c |
| *Acropora* cfr. *studeri* Brook | x | — |
| *Porites* sp. | — | x |

(x = species present; c = common)

known on the western side of the Pacific, where they are thought to be under most adverse conditions.

As an indication of the vigor of the corals at these places we may mention that stocks of *Turbinaria contorta* attain a size of 4 square meters, and those of *Hydnophora exesa* 2 square meters in surface extension in the Tateyama-wan, while those of *Cyphastrea chalcidicum*, *Favia speciosa* and *Echinophyllia* sp. as large as 1 square meter are by no means rare in the Enoura-wan.

*Stylophora* and *Cyphastrea*, which are in process of disappearance in Tahiti, exist in the Enoura-wan; and *Favites*, *Goniastrea*, *Maeandra*, and *Hydnophora*, absent in Tahiti, are found, some fairly common, in the Tateyama-wan or at Enoura.

These differences and another fact, pointed out by Crossland, that certain genera absent in Tahiti are found still farther eastward in the Taumotu Atolls are sufficient to show that the gradual decrease of the coral genera and species outwards from their centers of distribution is not simply due to the relative ability of their floating larvae to pass over considerable distances. Much depends on various other factors, partly intrinsic in each species, and partly local in origin and physico-chemical in nature.

Finally we call attention to a marvelous element of our coral fauna, a living species of the genus *Stylocoenia*,[36] which has been hitherto known only as a fossil, at horizons from the Neocomian to the Miocene.

[36] Yabe, H., and Sugiyama, T., A living species of *Stylocoenia* recently found in Japan: *Jap. Jour. Geol. Geog.*, vol. 9, no. 3, 1932.

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# NEW MIDDLE CAMBRIAN AGNOSTIAN TRILOBITES FROM VERMONT[1]

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ABSTRACT

Three new species of agnostian trilobites are described from the upper Middle Cambrian *Centropleura vermontensis* beds (St. Albans shale) of Vermont. Three new genera, two new subfamilies, and a new family are proposed.

For some years the writer has been studying the fauna of the upper Middle Cambrian *Centropleura vermontensis* zone in the St. Albans shale of northwestern Vermont. He has written a memoir in which the entire fauna is described, but as publication of this memoir is delayed, it seems desirable to describe a few of the species of the fauna now. Descriptions of three species have already been published.[2]

All of the specimens on which the species here described are based were collected from the narrow band of St. Albans shale that crops out north and south of St. Albans, Franklin County, Vermont.

## SYSTEMATIC DESCRIPTIONS

### Order AGNOSTIA Jaekel

### Family SPINAGNOSTIDAE Howell, n. fam.

Agnostians without medial furrow; frontal lobe of the glabella either well defined or more or less atrophied (sometimes quite obsolete), the main lobe almost clearly defined; axis of the pygidium usually well developed, although its lobation is often more or less indistinct and the whole axis is sometimes nearly obsolete. In some species in which the frontal lobe of the glabella is obsolete, the transverse furrow is preserved and truncates the front of the main lobe, but in others it is obsolete, and the front end of the main lobe is evenly rounded. All of the species have spines, or the beginnings of spines, on the flange of the pygidium.

The family appears to have lived from late Early Cambrian time until sometime in the early Late Cambrian epoch.

### Subfamily SPINAGNOSTINAE Howell, n. subfam.

Frontal lobe of the glabella so nearly obsolete that even the transverse furrow has nearly or entirely disappeared and the front of the main lobe is evenly rounded. Axis of the pygidium well defined, though without trace of lobation.

[1] Manuscript received January 19, 1935.

[2] Bryant, W. L., Evidence of the presence of chordates in the Cambrian: *Vermont State Geol., 15th Bienn. Rept. (1925–1926)*, pp. 125–126, pl. 12, 1927. Howell, B. F., Two new Cambrian trilobites from Vermont: *Wagner Free Inst. Sci. Philadelphia, Bull.*, vol. 7, pp. 4–8, 1932.

Only the single genus defined below is known to be referable to the subfamily.

Genus SPINAGNOSTUS Howell, n. gen.

Characters of the genus are those of the subfamily. Genotype and only known species, *S. franklinensis.*

SPINAGNOSTUS FRANKLINENSIS Howell, n. sp.
Plate 22, figures 1–5

Cephalon: Brim and anterior groove both broad; no trace of the frontal lobe of the glabella, but main lobe is long and well defined all around; seldom any trace of the transverse furrow, the main lobe being usually well rounded in front. A small spine at each of the rear corners of the shield; convexity moderate; test smooth. Young cephalon like adult in form.

Thorax: Bosses and furrows not strongly developed.

Pygidium: Flange rather wide, armed with two stout spines; axis well defined by the dorsal furrow, without transverse furrows; tubercle present, not conspicuous. Axis very bluntly pointed at the rear, reaching the posterior groove and separating the pleural lobes. Convexity of the shield moderate; test smooth. Axis of young pygidium shorter and narrower than adult, with pleural lobes confluent.

*Observations.*—This is one of the most common species in the *Centropleura vermontensis* beds and is the most common agnostian.

*Types.*—Holotype, cephalon, Princeton Univ. no. 9679 a. Paratypes, Princeton Univ. nos. 9680–9702, 9808, 40201; Peabody Mus. Yale Univ. nos. 13402–13408, 13432, 13437; Canadian Nat. Mus. nos. 6454 a–d, 6455; U. S. Nat. Mus. Tophomeotypes, Univ. Vermont; Redpath Mus. McGill Univ.; Walker Mus. Univ. Chicago; Univ. Alberta; Columbia Univ.; Am. Mus. Nat. Hist.; Mus. Comp. Zool. Harvard Univ.; British Mus. (Nat. Hist.); Mus. Geol. Survey Great Britain; Sedgwick Mus.Cambridge Univ.; Mus. Geol. Survey Denmark; Mus. Geol. Survey Sweden; Paleont. Mus. Univ. Lund; Národní Mus. Prague; Mus. Geol. Survey Poland; Paleont. Mus. Univ. Göttingen; Senckenberg Mus. Frankfort; Geol.-paläont. Inst. Univ. Berlin; Univ. Montpellier.

## Subfamily QUADRAGNOSTINAE Howell, n. subfam.

Glabella is bilobed, defined all around by the dorsal furrow, and crossed by a well developed transverse furrow. Axis well defined all around by the dorsal furrow; transverse furrows in some species fairly well developed, in other species nearly, or quite, obsolete. Well developed spines on the flange.

Genus QUADRAGNOSTUS Howell, n. gen.

Frontal lobe of the glabella subquadrate, as wide as the main lobe, or only a little narrower and slightly pointed. Brim very wide, and the whole pygidium long and lanceolate. Pleural lobes nearly, or quite, separated at the rear. Flange wide and armed with spines, and the pygidium subquadrate. Convexity of both shields low; surface smooth; shields large in some species. Genotype, *Q. solus.*

QUADRAGNOSTUS SOLUS Howell, n. sp.
Plate 22, figures 6, 7

Cephalon: Frontal lobe of glabella rounded in front, main lobe indented on the side about half way along its length; transverse furrow strongly arched backward.

Thorax: Unknown.

Pygidium: Axis long and narrow, separating the pleural lobes at the rear; very faint traces of transverse furrows. Tubercle high, very much elongated, keel-shaped. Pleural lobes and flange very wide; large spines on the flange, so that whole shield has a broad, subquadrate outline. Convexity of shield moderate, surface smooth.

*Observations.*—One cephalon and five pygidia have been discovered, the species being a rare member of the St. Albans fauna. It is possible, but not probable, that the cranidium assigned to this spe-

cies belongs to some other agnostian, for its frontal glabellar lobe is less quadrate than might be expected of the cephalon of a species with a pygidium such as that on which *Q. solus* is founded.

*Types.*—Holotype, Princeton Univ. no. 9793; paratypes, same collection, nos. 9794, 9943, 40091, 40126.

## Family PHALACROMIDAE Corda

The family Leiagnostidae was proposed by Jaekel[3] in 1909 for agnostians with shields ovally convex, smooth or with rudimentary furrows, indicating the position of the glabella, pygidium with a flat flange, without spines; and the pleura of the thorax without lateral bosses. Jaekel included in his new family the species which Tullberg[4] had placed in 1880 in his group Laevigati. Jaekel referred several species to the Leiagnostidae, at the same time assigning them to new genera: *Agnostus laevigatus*, genotype of *Miagnostus*, to which he also referred *A. cicer;* a new species, *erraticus*, genotype of *Leiagnostus*, in which he placed also *A. nudus*, *A. nudus* var. *scanicus*, and *A. glandiformis*. The species of *Miagnostus* were said by Jaekel to be characterized by the possession of short glabellar furrows, those of *Leiagnostus* by lack of any trace of furrows on the shields.

The writer believes that the species *erraticus*, *nudus*, *nudus* var. *scanicus*, and *glandiformis* do not all belong to a single genus or subfamily, but that the Ordovician *Leiagnostus erraticus* should be separated from *nudus* and *nudus scanicus*. These Middle Cambrian species should be classified in Phalacromidae, in the genus *Phalacroma*, groups proposed in 1847 by Corda.[5] *Agnostus glandiformis*,

[3] Jaekel, O., Uber die Agnostiden: *Deutsche geol. Gesell., Zeitschr.*, vol. 61, pp. 380–401, 1909.

[4] Tullberg, S. A., Om Agnostus-arterna i de kambriska aflagringarne vid Andrarum: *Sveriges Geol. Unders.*, ser. C, no. 42, 1880.

[5] Corda, J. A. C., *Prodrom einer Monographie der böhmischen Trilobiten*, p. 43, 1847.

### EXPLANATION OF PLATE 22

FIGS. 1–5—*Spinagnostus franklinensis* Howell, n. gen. and sp. 1, Holotype cephalon, ×5 (Princeton Univ. no. 9679a. 2), Paratype cephalon, ×5 (Princeton Univ. no. 9682). 3, Paratype thorax and pygidium, ×6 (Princeton Univ. no. 9680.) 4, 5, Paratype pygidia (Princeton Univ. nos. 9683, 9686). (p. 219)

6–7—*Quadragnostus solus* Howell, n. gen. and sp. 6, Holotype pygidium, ×4 (Princeton Univ. no. 9793). 7, Paratype cephalon, ×6 (Princeton Univ. no. 40126). (p. 219)

8–11—*Grandagnostus vermontensis* Howell, n. gen. and sp. 8, Holotype cephalon, ×2 (Princeton Univ. no. 9736). 9, Paratype cephalon, ×2 (Princeton Univ. no. 9754). 10, Paratype thorax and pygidium, ×5 (Princeton Univ. no. 9757). 11, Paratype pygidium, ×2 (Princeton Univ. no. 9837). (p. 221)

12–15—*Calodiscus foveolatus* Howell, n. gen. and sp. 12, Holotype cephalon, ×6 (Univ. Montpellier no. A130, 1). 13, Paratype cephalon, ×6 (Princeton Univ. no. 41242). 14, Paratype pygidium, ×6 (Miquel Coll. no. A130, 3). 15, Paratype cephalon and pygidium, ×6 (Miquel Coll. no. A130, 5). (p. 224)

16—*Peronopsis miqueli* Howell, n. sp., holotype pygidium, ×4 (Miquel Coll. no. H1). (p. 226)

17–18—*Peronopsis sallesi* (Munier-Chalmas and Bergeron). 17, Plesiotype, entire test, ×4 (Princeton Univ. no. 41195). 18, Plesiotype, entire test, ×5 (Coll. Giraud, Univ. Montpellier no. H2). (p. 226)

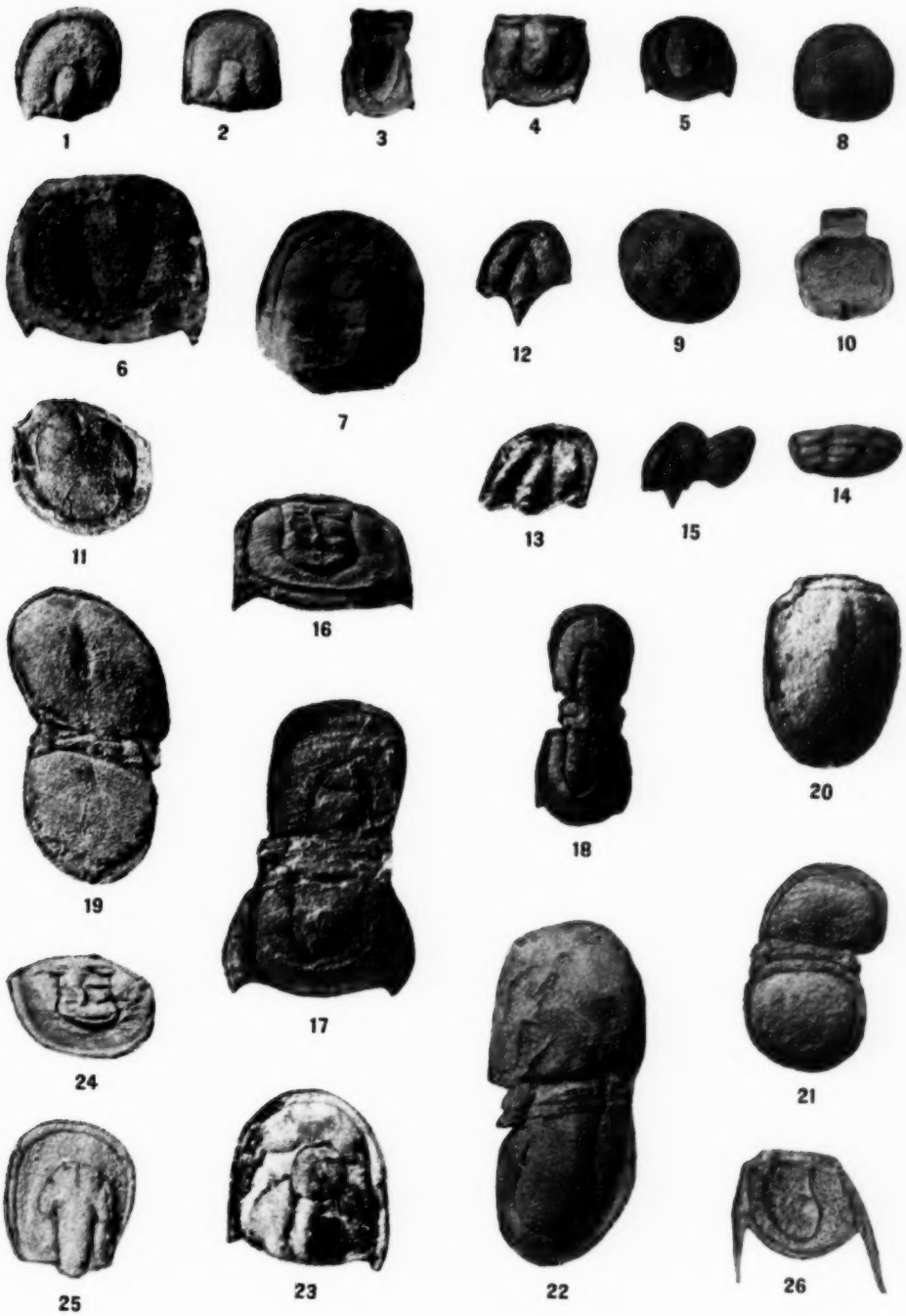
19–20—*Phalacroma thorali* Howell, n. sp. 19, Holotype, entire test, ×3½ (Univ. Montpellier no. H3). 20, Paratype pygidium, ×5 (Princeton Univ. no. 41413). (p. 227)

21—*Gallagnostus geminus* Howell, n. gen. and sp., holotype, entire test, ×5 (Miquel Coll. no. H13). (p. 227)

22—*Platagnostus immensus* Howell, n. gen. and sp., holotype, entire test, ×2½ (Thoral Coll. no. H14). (p. 228)

23–24—*Condylopyge imperator* Howell, n. sp. 23, Holotype cephalon, ×5 (Thoral Coll. no. H15). 24, Paratype pygidium, ×5 (Thoral Coll. no. H16). (p. 229)

25–26—*Pleuroctenium magnificum* Howell, n. sp. 25, Holotype cephalon, ×5 (Thoral Coll. no. H17). 26, Paratype pygidium, ×5 (Thoral Coll. no. H19). (p. 229)




Howell, Cambrian and Ordovician Trilobites

of the later Middle Cambrian, is placed below in another genus of the Phalacromidae.

Genus GRANDAGNOSTUS Howell, n. gen.

Characterized by its large size (its species are among the largest of all agnostians), its almost, or quite, smooth shields, the absence of a well developed brim on the adult cephalon, and the presence of a rather broad, or at least, well developed, flange on the pygidium.

Genotype, *G. vermontensis*, n. sp. *Agnostus glandiformis* Angelin (*Leiagnostus g.* Jaekel, 1909) is also placed in the genus.

Species of *Grandagnostus* are known only from late Middle Cambrian, *G. glandiformis* being known only from the *Paradoxides forchhammeri* zone of Scandinavia, and Bennett Island, Siberia; and *G. vermontensis*, only from the *Centropleura vermontensis* zone of Vermont.

GRANDAGNOSTUS VERMONTENSIS Howell, n. sp.
Plate 22, figures 8–11

Cephalon: Only faint traces of the basal lobes and the rear ends of the dorsal furrow, and even these can not be seen on most of the specimens. No clearly developed brim on any of the known adult cephala, all of which are exfoliated; unexfoliated young cephala undoubtedly referable to this species exhibit none, though one small unexfoliated shield probably assignable to this form does have a narrow brim. Distinct median tubercle. Convexity rather low; test smooth.

Thorax: Only the axis known; smooth.

Pygidium: About as convex as the cephalon; no trace of a dorsal furrow, but with well developed flange; test smooth.

*Observations.*—This species differs from *G. glandiformis* in its shorter and somewhat less quadrate shields and in its smaller size. The flange of the pygidium seems also to be not as wide as in *G. glandiformis*. These differences may, however, be due to the form of preservation of our specimens, as shields of *G. vermontensis* or a closely related species, more like *G. glandiformis* but not as large, occur in limestone pebbles of St. Albans age in the Upper Cambrian Mill River conglomerate of northwestern Vermont. No trace of the remarkable doublures of *G. glandiformis*[6] was found on any of the specimens from the St. Albans shale, but they are present on some of the specimens from the Mill River conglomerate.

*G. vermontensis*, though smaller than *G. glandiformis*, is very large for an agnostian, being one of the largest species of the order yet found. It is not nearly as common as *Spinagnostus franklinensis*, but is more frequently seen than the other five agnostians in the St. Albans beds.

*Types.*—Holotype, cephalon, Princeton Univ. no. 9736. Paratypes, Princeton Univ. nos. 9737–9757, 9837, 9850, 9851; Peabody Mus. Yale Univ. nos. 13409–13412, 1422; Canadian Nat. Mus. nos. 6456–6459; U. S. Nat. Mus. Tophomeotypes, Univ. Vermont; Walker Mus. Univ. Chicago; Národní Mus. Prague; Mus. Geol. Survey Denmark.

[6] Holm, G., and Westergaard, A. H., A Middle Cambrian fauna from Bennett Island: *Acad. Sci. U.R.S.S., Mém.*, ser. 8, cl. phys.-math., vol. 21, no. 8, p. 11, pl. 4, figs. 1–3, 1930.

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# CAMBRIAN AND ORDOVICIAN TRILOBITES FROM HÉRAULT, SOUTHERN FRANCE[1]

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ABSTRACT

From the lower *Paradoxides* beds (Middle Cambrian) of Hérault, France, are described a new eodiscid trilobite and 4 new genera and 7 new species of agnostian trilobites; from the Tremadocian (Lower Ordovician) beds, 2 new genera, 2 new species, and a new variety of agnostians; from the lower Arenigian (Lower Ordovician) beds, a new genus, 7 new species, and a new variety of agnostians; from the middle and upper Arenigian *Calymene* shales (Lower Ordovician), 4 new species of agnostians. The classification of some of the agnostians is discussed and 5 new families are proposed.

Through the kindness of Dr. Marcel Thoral, of the University of Montpellier, who is studying the Early Paleozoic rocks of Hérault, France, the writer has been permitted to describe a collection of trilobites from the region, including a new eodiscid and a number of new agnostian trilobites. The specimens studied were collected by Doctor Thoral, M. Jean Miquel, and M. Guiraud in the Montagne Noire region and the Monts de Lacaune. The writer desires to acknowledge here his indebtedness to these gentlemen and to Professor Joseph Blayac, of the University of Montpellier, for making available the collection for examination and for many courtesies extended during a visit to Hérault in 1931.

The species treated in this paper are as follows:

*Paradoxides* beds (Middle Cambrian)
- *Calodiscus foveolatus* Howell, n. gen. and sp.
- *Peronopsis sallesi* (Munier-Chalmas and Bergeron)
- *P. miqueli* Howell, n. sp.
- *Phalacroma thorali* Howell, n. sp.
- *Gallagnostus geminus* Howell, n. gen. and sp.
- *Platagnostus immensus* Howell, n. gen. and sp.
- *Condylopyge imperator* Howell, n. sp.
- *Pleuroctenium magnificum* Howell, n. sp.
- *Fallagnostus blayaci* Howell, n. gen. and sp.

Tremadocian beds (Lower Ordovician)
- *Geragnostus sidenbladhi* (Linnarsson) var. *gallicus* Howell, n. gen. and var.
- *G. ambiguus* Howell, n. sp.
- *Anglagnostus barroubioensis* Howell, n. gen. and sp.

Lowest Arenigian beds (Lower Ordovician)
- *Geragnostus occitanus* Howell, n. sp.
- *G. callavei* (Raw) var. *mediterraneus* Howell, n. var.
- *G. pusio* Howell, n. sp.
- *Trinodus chinianensis* Howell, n. sp.
- *T. oviformis* Howell, n. sp.
- *T. corpulentus* Howell, n. sp.
- *T. abruptus* Howell, n. sp.
- *Micragnostus languedocensis* Howell, n. gen. and sp.

Middle and upper Arenigian *Calymene* shales (Lower Ordovician)
- *Leiagnostus foulonensis* Howell, n. sp.
- *Geragnostus languidus* Howell, n. sp.

[1] Manuscript received January 19, 1935.

*G. boutouryensis* Howell, n. sp.
*G. manifestus* Howell, n. sp.

The genus *Mallagnostus* Howell, n. gen., is instituted for *M. desideratus* (Walcott), Lower Cambrian, North America.

### I. A NEW EODISCID FROM THE MIDDLE CAMBRIAN PARADOXIDES BEDS

M. Miquel, who has worked for many years on the Paradoxides beds of Coulouma, called attention in 1905 to the presence in them of an eodiscid trilobite, as "*Microdiscus*."[2] Seven years later[3] he again referred to these fossils, stating that they occur in the "Acadien inférieur," the lowest zone of the *Paradoxides* beds at Coulouma, in association with *Paradoxides rouvillei* and other species. He thought that two species of "*Microdiscus*" were represented, which he listed as "*Microdiscus* cf. *sculptus* Hicks" and "*Microdiscus* nov. sp., du groupe du *M. punctatus* Salter."

"*Microdiscus*" *sculptus* occurs in the Harlech formation of South Wales, which is of early Medial Cambrian age. "*M.*" *punctatus* is a later Medial Cambrian species found in the Menevian of Wales. As only a single species of eodiscid trilobites seems to be represented in the material submitted to the writer by Doctor Thoral, it seems probable that M. Miquel's "*Microdiscus* cf. *sculptus*" was based on the more strongly ribbed of two types of pygidia noted by him in 1905, and that his "*Microdiscus* nov. sp." was founded on a cephalon and the other type of pygidium. The writer believes that the cephalon and the more strongly ribbed pygidium belong to the single species described below; and he assumes that the other pygidium referred by M. Miquel to "*Microdiscus*" is probably not that of an eodiscid, but belongs to some other kind of trilobite.

The genus *Microdiscus* was founded on a young example of *Cryptolithus* and therefore cannot be used for the small trilobites to which it was for many years applied. In 1913 Raymond[4] revived *Eodiscus* Matthew to "include a part, at least, of the species now known as *Microdiscus*." Later in the same year[5] he divided the family Eodiscidae into three genera, *Eodiscus* Matthew, *Goniodiscus* Raymond, and *Weymouthia* Raymond. He chose *Microdiscus lobatus* Hall as the genotype of *Goniodiscus*, and also placed in this genus *M. dawsoni* Hartt, New Brunswick; *M. parkeri* Walcott, Vermont; and *M. sculptus* Hicks, Wales. He stated that *Goniodiscus* is characterized by "a long glabella, usually blunt neck spine, and pygidium with rings on the axial lobe and ribs on the pleural lobes." The name *Gon-*

[2] Miquel, Jean, Essai sur le cambrien de la Montagne Noire. Coulouma-l'Acadien: *Soc. géol. France, Bull.*, ser. 4, vol. 5, p. 472, 1905.

[3] Miquel, Jean, Nouvel essai sur la géologie des terrains primaires du département de l'Hérault: classification des terrains siluriens: *Soc. études sci. nat. (Béziers), Bull.*, no. 34, p. 9, 1912.

[4] Raymond, P. E., Some changes in the names of genera of trilobites: *The Ottawa Naturalist*, vol. 26, p. 139, 1913.

[5] Raymond, P. E., On the genera of the Eodiscidae: *The Ottawa Naturalist*, vol. 27, pp. 101–106, 1913.

*iodiscus*, however, had been used in 1842 by Müller and Troschel for an asteroid, as noted by Cobbold.[6] The writer suggested to Professor Raymond that he propose a new name for the genus, but he has asked the writer to do this, and accordingly the name *Calodiscus* is here proposed to replace *Goniodiscus* Raymond, not Müller and Troschel. The species *lobatus* Hall becomes the genotype of *Calodiscus*.

Cobbold believed that *Calodiscus* ("*Goniodiscus*") is not distinct from *Eodiscus*. The writer agrees with him that the length of the glabella, which Raymond used as a distinguishing character, is not a sufficiently diagnostic feature to justify separating the two genera. After examining many specimens of various species of eodiscids, however, the writer is convinced that the presence or absence of "ribs" on the pleural lobes of the pygidium, the value of which as a generic character Cobbold doubted, is actually of generic value. Because of this conviction, and because the species which Raymond placed in "*Goniodiscus*" — *lobatus*, *dawsoni*, *parkeri*, and *sculptus*—as well as the species here described, are all of late Early Cambrian or early Medial Cambrian age, he believes it best to retain the group as a genus. He is not sure that *sculptus*, *dawsoni*, and *foveolatus*, which appear to be closely related, belong in the same genus with *lobatus* and *parkeri;* and it may be that they should be separated. It is possible, too, that the species, *precursor* and *meeki*, which Raymond has assigned to *Eodiscus*, but whose pygidia are unknown, may prove to belong rather in *Calodiscus* or in a new genus with *sculptus*, *dawsoni*, and *foveolatus*. He hopes at some future time to be able to throw more light on the problem of the classification of the Eodiscidae; but he feels that until that time it is best to go no farther than he has gone here with changes of nomenclature in this family.

[6] Cobbold, C. S., Additional fossils from the Cambrian rocks of Comley, Shropshire: *Geol. Soc. London, Quart. Jour.*, vol. 87, p. 460, 1931.

## Family EODISCIDAE Raymond

### Genus CALODISCUS Howell, n. gen.

CALODISCUS FOVEOLATUS Howell n, sp.
Plate 22, figures 12–15

Cephalon: Approximately semicircular in outline, except for a neck spine, which projects backward about one-fourth the length of the rest of the shield. Brim thickened, separated from the cheeks by a well developed marginal groove. Cheeks and glabella highly convex, narrow, and pointed anteriorly. Glabella about the size and shape of a single cheek; no trace of glabellar furrows; dorsal furrow strongly developed, cheeks well separated in front. Four little tubercles on the rear border of the shield, one near each genal angle and one at the inner rear corner of each cheek; no other tubercles on the brim, but a series of poorly developed furrows cross the marginal furrow at right angles. The whole shield is approximately 3 mm. long and 3 mm. wide. Test smooth.

Thorax: Unknown.

Pygidium: Whole shield short, wide, and rather convex; rear edge arched a little forward just behind the axis. Flange narrow, thickened, and separated from the pleural lobes by a well developed marginal groove. The bluntly triangular axis very prominently divided into three

lobes by deep transverse furrows; pleural lobes likewise divided by deep furrows into three ribs; axis and each of the two pleural lobes of about the same size, shape, and appearance; pleural lobes are not confluent behind, the axis reaching to the marginal groove. Whole shield about 1.5 mm. long, 3 mm. wide. Test smooth.

*Observations.*—The nearest known relatives of this species would appear to be *Calodiscus dawsoni*, of the *Paradoxides lamellatus* zone of New Brunswick and the *Paradoxides bennetti* zone of Newfoundland, and *Calodiscus sculptus*, of the Harlech of South Wales. The cephalon of *C. sculptus* is too imperfectly known to permit detailed comparison with that of *C. foveolatus*; but the pygidium is better known, and differs from that of the French species in having one more rib on the pleural lobes and two more segments in the axis, the axial segments of the Welsh species each bearing also two tubercles. The cephalon of *C. dawsoni* differs from that of *C. foveolatus* in its much thickened brim crossed by well developed furrows, in its granular cheek surface, and in its longer neck spine. The pygidium differs in having five ribs on each pleural lobe and six segments in the axis, each with a single tubercle on its highest point.

*Types.*—Holotype, cephalon, Univ. Montpellier (Collection Thoral) no. A130, 1. Paratypes, cephala and pygidia, Univ. Montpellier (Collection Miquel) nos. A130,2; A130,6; Princeton Univ. nos. 41234–41242, 41418.

*Age and locality.*—Early "Acadian" (probably early Paradoxidian), Middle Cambrian; Coulouma, Montagne Noire. (Thoral's locality "Champ du Travers 1ère Ravine," and Miquel's locality "La Vigne Cauquil.")

## II. AGNOSTIAN TRILOBITES FROM THE MIDDLE CAMBRIAN PARADOXIDES BEDS

The Cambrian *Paradoxides* beds of the Montagne Noire region have been described in a number of publications.[7] Thoral has been doing field work on these strata for some years, and will publish his results soon. *Paradoxides* beds have only recently been discovered and described by Thoral in the Monts de Lacaune.[8]

The *Paradoxides* beds of the Montagne Noire region are spoken of by French geologists as being of "Acadian" age. They were divided by the earlier stratigraphers into lower, middle, and upper Acadian stages. All but one of the eight species of agnostians described below were collected from beds of the middle Acadian stage. That single species, *Peronopsis miqueli*, was secured from the shales of the lower Acadian stage. Only one of the eight species, *Peronopsis sallesi*, has been described

[7] Munier-Chalmas, E. P., and Bergeron J., *Étude géologique du massif ancien situé au sud du Plateau Central*, Paris, 1889. Rouville, P. G., Delage, A., and Miquel, J., Les terrains primaires de l'arrondissement de Saint-Pons (Hérault): *Acad. sci. lett. Montpellier, sect. sci., Mém.*, ser. 2, vol. 2, no. 1, 1894. Miquel, Jean, Essai sur le cambrien de la Montagne Noire: Coulouma-l'Acadien: *Soc. géol. France, Bull.*, ser. 4, vol. 5, pp. 465–483, pl. 15, 1905; Nouvel essai sur la géologie des terrains primaries du departement de l'Hérault: classification des terrains siluriens: *Soc. études sci. nat. (Béziers), Bull.*, no. 34, 1912. Blayac, Joseph, and Daguin, M. F., Revision de la feuille de Bédarieux au 80,000e: notes de stratigraphie et de tectonique sur les terrains primaires de la Montagne Noire, à l'ouest de l'Orb: *Carte géol. France, Bull.*, vol. 24, no. 146, pp. 1–11, 1922. Coulouma, J., and Miquel, J., Le bassin de la Cesse, 1ère partie: *Bull. géogr. Languedoc*, reprint, pp. 27–29, 1933.

[8] Thoral, Marcel, Nouvelle contribution à la stratigraphie du cambrien et du silurien de la partie orientale des Monts de Lacaune: *Acad. Sci. Paris, Comptes rend.*, vol. 194, pp. 1671–1673, 1932.

before, although the presence of other species in these beds has been noted, and the resemblance of one of them, *Phalacroma thorali*, to the Scandinavian species described by Angelin as *Agnostus glandiformis*, and the similarity of another, *Condylopyge imperator*, to *C. rex*, of Bohemia, have been pointed out by M. Miquel.

## SYSTEMATIC DESCRIPTIONS

## Order AGNOSTIA Jaekel

## Family SPINAGNOSTIDAE Howell

## Subfamily QUADRAGNOSTINAE Howell

### Genus PERONOPSIS Corda

#### PERONOPSIS MIQUELI Howell, n. sp.

Plate 22, figure 16

Only the pygidium is known; subquadrate; flange of moderate width, bearing a blunt spine at each of its two rear corners; axis broad, bluntly pointed at the rear; pleural lobes narrowly confluent behind. Axis crossed by two transverse furrows, the anterior arching forward; tubercle long, crossing both furrows. Convexity of the whole shield medium, axis not rising much above the general level; test smooth.

*Observations.*—The pygidium of this species resembles that of *Peronopsis trilobatus* (Matthew), of the *Paradoxides lamellatus* zone of New Brunswick, but the axis of the Canadian form is longer and more pointed and separates the pleural lobes at the rear; and the transverse furrows are more strongly developed. The two species belong to the same section of the genus *Peronopsis*, but they are sufficiently different to deserve full specific rank. Species of *Peronopsis* of this sort appear to have been characteristic members of the early Paradoxidian faunas of the North Atlantic region.

*Types.*—Holotype, Univ. Montpellier (Collection Miquel) no. H1. The only other specimens known to the writer are three paratypes, Princeton Univ. nos. 41156, 41233, 41242.

*Age and locality.*—"Early Acadian" (probably early Paradoxidian); "La 2ème Ravine du Travers" of Miquel, and "Champ du Travers Ravine Est" and "Champ du Travers 1ère Ravine" of Thoral, at Coulouma, Montagne Noire.

#### PERONOPSIS SALLESI (Munier-Chalmas and Bergeron)

Plate 22, figures 17, 18

*Agnostus sallesi* MUNIER-CHALMAS and BERGERON, *1889*, Étude géologique du massif ancien situé au sud du Plateau Central, pp. 337–338, pl. 3, fig. 5.

Cephalon: Brim broad, especially around the front; shield with the usual subrectangular shape. Transverse furrow on the glabella faint; basal lobes large. Whole shield of medium convexity; surface smooth.

Thorax: Thorax as ordinarily found in *Peronopsis*.

Pygidium: Subquadrate; convexity medium; test smooth. Flange wide, with large, blunt, spines on its rear corners. Axis tapering evenly backward to a blunt point, not separating the pleural lobes at the rear; with an elongate tubercle; no clear transverse furrows, though faint traces of two such furrows can sometimes be detected, especially in young shields.

*Observations.*—This species is characterized by the faintness of its transverse furrows and its large size, some shields attaining a length of 8 mm. It is comparable with other species of *Peronopsis* found in middle Paradoxidian strata elsewhere in Europe. The figure and description of this species published by Munier-Chalmas and Bergeron are not accurate. They do not indicate the presence of a transverse furrow on the glabella, and they show the axis of the pygidium as shorter than it really is.

*Types.*—The holotype is in the Laboratoire de Géologie, the Sorbonne, Paris. Plesiotypes, Univ. Montpellier nos. H2, H22–H27, H34–H41; Princeton Univ.

nos. 41157–41164, 41172, 41173, 41195. 41196, 41411, 141414.

*Age and locality.*—Late "middle Acadian" (Paradoxidian) of "la 1ère Ravine du Travers" of Miquel ("la 3ème Ravine du Travers," "Champ du Travers 3ème Ravine" of Thoral), and Chemin du Banc du Touring-Club, Chemin du Col de Treilles, and the Châtaigneraie Théron, all at Coulouma, Hérault. Also in late "middle Acadian" beds at Ferrals-les-Montagnes, Hérault, and the "middle Acadian" zone of *Paradoxides mediterraneus* and *Solenopleura rouayrouxi* between Favayroles and Cousse, Hérault.

## Family PHALACROMIDAE Corda

### Genus PHALACROMA Corda

#### PHALACROMA THORALI Howell, n. sp.
Plate 22, figures 19, 20

Cephalon: Whole shield smooth, of low and even convexity; no clear trace of a glabella, basal lobes, nor, as far as can be determined from the specimens studied, of a well developed brim (one specimen shows some faint evidence of having had a brim, however); only the faintest trace of a tubercle.

Thorax: Of the type characteristic of *Phalacroma*, the axial portion of the segments smooth.

Pygidium: Convexity low and even; surface smooth, except for a small, elongate, tubercle; flange wide, especially at the rear.

*Observations.*—The specimens assigned to this species vary a good deal in size and shape, but, as the extremes of variation are connected by intermediate links, it seems probable that all of them are referable to a single species. The smaller individuals are characteristic examples of *Phalacroma*. The larger ones, however, do not have the flange relatively so wide, and somewhat resemble *Grandagnostus vermontensis* Howell (p. 000), of the *Centropleura vermontensis* fauna of Vermont. *P. thorali* apparently connects *Phalacroma* and *Grandagnostus*. Some of the shields of *P. thorali* are as much as 10 mm. long, *G. vermontensis* attains about the same size, and *G. glandiformis* grows even larger. *P. thorali* differs from *P. nudum*, the genotype of *Phalacroma*, in its larger size and in details of form. Its pygidium differs from that of *G. vermontensis* in its less quadrate form, its less convex adult stage, and its wider flange.

*Types.*—Holotype, entire test, Univ. Montpellier no. H3. Paratypes, Univ. Montpellier nos. H4–H12, H28–H33; Princeton Univ. nos. 41165–41169, 41412 41413.

*Age and locality.*—Late "middle Acadian" (Paradoxidian) of "la 1ère Ravine" of Miquel ("la 3ème Ravine du Travers," "Champ du Travers 3ème Ravine" of Thoral), Chemin du Banc du Touring-Club, and the Châtaigneraie Théron, all at Coulouma, Hérault. Also "middle Acadian," zone of *Paradoxides mediterraneus* and *Solenopleura rouayrouxi*, between Favayroles and Cousse, Hérault.

### Genus GALLAGNOSTUS Howell, n. gen.

Cephalon smooth; convexity low to medium; brim of medium width; no trace of a glabella or a dorsal furrow. Pygidium smooth; convexity low to medium; flange of medium width. Both shields as broad as long. Axial portion of thorax wide. Genotype, *Gallagnostus geminus*, described below. *Agnostus boliviensis* Hoek and *A. iruyensis* Kayser are also placed in this genus.

#### GALLAGNOSTUS GEMINUS Howell, n. sp.
Plate 22, figure 21

Cephalon: Convexity rather low; no trace of a tubercle on the two known specimens.

Thorax: As nearly as can be determined from the two known examples, the axial portion was quite smooth.

Pygidium: Of approximately the same shape and convexity as the cephalon; flange about as wide as the brim; no trace of a tubercle on either of the three known pygidia.

*Observations.*—Although this species lived in Middle Cambrian time, what

appear to be its nearest known relatives, *G. boliviensis*, from the border between Argentina and Bolivia, and *G. iruyensis*, of Argentina, are said to occur in Upper Cambrian rocks. Of the two South American species, *G. boliviensis* would appear to be the more similar to *G. geminus*, as both it and *G. geminus* seem to lack a tubercle on the pygidium and are small species, only about 6 mm. long, over all. The brim and flange of *G. geminus* were apparently a little wider than were those of *G. boliviensis*, and, if the published figure of *G. boliviensis* is correct, the pygidium of *G. geminus* was a little longer in proportion to its width, and a little more ovoid at its rear end than was the pygidium of the Bolivian species. *G. iruyensis*, in addition to having a tubercle on the pygidium, probably differed from *G. geminus* in having the pygidium more convex.

*Types.*—Holotype, entire test, Univ. Montpellier (Collection Miquel) no. H13. Paratypes, a pygidium and an entire test, Princeton Univ. nos. 41170, 41171.

*Age and locality.*—Late "middle Acadian" (Paradoxidian) of "la 1ère Ravine du Travers" of Miquel ("Champ du Travers 3ème Ravine" of Thoral), Chemin du Col de Treilles, Banc du Touring-Club, Coulouma, Hérault.

## Family PLATAGNOSTIDAE Howell n. fam.

The characters of this family are those of its only known genus, *Platagnostus*.

### Genus PLATAGNOSTUS Howell, n. gen.

Cephalon with a smooth surface, narrow brim; only the rear end of the glabella indicated by the ends of the dorsal furrow. Pygidium of even convexity; axis very wide and expanded at the rear, where it reaches the posterior groove. Genotype, *Agnostus bibullatus* (Barrande).

PLATAGNOSTUS IMMENSUS Howell, n. sp.
Plate 22, figure 22

Cephalon: Convexity low; surface smooth; only trace of a glabella the two faint rear ends of the dorsal furrow; no basal lobes and no tubercle on the single known cephalon; brim narrow.

Thorax: Axial portion of the segments almost smooth, as in the genotype.

Pygidium: Whole shield of low and even convexity; test smooth. Axis tongue shaped, broader at the rear than at the front, evenly rounded behind; clearly defined by the dorsal furrow along its sides, but only faintly around its rear end, where it reaches the posterior groove; flange of medium width.

*Observations.*—Although this species is a great deal larger than *P. bibullatus*, it so similar to that species that it would seem to be undoubtedly congeneric with it. The anterior portion of the axis of the pygidium is more constricted than in *bibullatus*.

*Type.*—Holotype and only known specimen, an entire test, Univ. Montpellier (Collection Thoral) no. H14; casts, Princeton Univ. no. 41185, U. S. Nat. Museum.

*Age and locality.*—Late "middle Acadian" (Paradoxidian), Middle Cambrian, of the "niveau intermediaire," Chemin du Col de Treilles, Banc du Touring-Club, Coulouma.

## Family MALLAGNOSTIDAE Howell, n. fam.

Agnostians with the anterior lobe of the glabella wider than the main lobe and the rear part of the axis of the pygidium slightly expanded and evenly rounded.

### Genus MALLAGNOSTUS Howell, n. gen.

The genus *Mallagnostus* is here proposed to receive *Agnostus desideratus* Walcott, part.[9] *M. desideratus* occurs in rocks of Early Cambrian age in eastern North America, and is characterized by a pygidium which resembles that of

[9] Walcott, C. D., The fauna of the Lower Cambrian or *Olenellus* zone: *U. S. Geol. Survey, 10th Ann. Rept.*, pt. 1, p. 629, pl. 80, fig. 5 only, 1890 (1891).

*Condylopyge* Corda in general form, but has a smaller axis. The holotype pygidium of this species was figured by Walcott as a cephalon, but the cephalon is unknown.

### Genus CONDYLOPYGE Corda

#### CONDYLOPYGE IMPERATOR Howell, n. sp.
Plate 22, figures 23, 24

*Agnostus* cf. *rex* (Barrande) COULOUMA and MIQUEL, *1933*, Le Bassin de la Cesse: *Bull. Géogr. Languedoc*, reprint, p. 28.

Cephalon: Whole shield spatulate, more ellipsoidal in front than in *C. rex* (Barrande), of Bohemia. Anterior lobe of glabella subhexagonal, not triangular as in *C. rex;* tiny spines at the rear corners of the shield; no distinct basal lobes in the single known cephalon; main lobe of the glabella narrowed at the rear; basal lobes may have merged with the cheeks. Convexity of whole shield low; surface smooth.

Thorax: Unknown.

Pygidium: Single known pygidium referred to this species with smooth test, more convex than the cephalon; axis somewhat shorter and blunter than in *C. rex*, though this may be, at least in part, due to longitudinal compression of the shield. Dorsal and transverse furrows deep; tubercle long and well developed.

*Observations.*—Only a single cephalon and a single pygidium of this species are known, neither well preserved. The pygidium differs little from that of *C. rex*, but the cephalon appears to differ from those of all known species of *Condylopyge* in that the anterior lobe of the glabella, though wider than the main lobe, is not so distinctly triangular, the rear corners being truncated and the front less pointed and more rounded than is usual.

*Types.*—Holotype, cephalon, Univ. Montpellier (Collection Thoral) no. H15; counterpart, Princeton Univ. no. 41415. Paratype, pygidium, Univ. Montpellier (Collection Thoral) no. H16; counterpart, Princeton Univ. no. 41416.

*Age and locality.*—The holotype is from a "middle Acadian" buff shale with *Paradoxides mediterraneus* and *Solenopleura rouayrouxi* between Favayroles and Cousse, Hérault. The paratype was collected from an olive gray shale of early "middle Acadian" age, with *Conocoryphe heberti* and *Acrothele bergeroni*, at Melagues, Monts de Lacaune, Aveyron. The horizon of the pygidium is probably somewhat below that of the cephalon, and it is possible that future collecting will prove that the pygidium is referable to another species.

### Genus PLEUROCTENIUM Corda

#### PLEUROCTENIUM MAGNIFICUM Howell, n. sp.
Plate 22, figures 25, 26

Cephalon: Similar to *P. granulatum* (Barrande), of Bohemia, but the shield a little more ovoid in front, and thus less quadrate in general form; main lobe of glabella narrower.

Thorax: Unknown.

Pygidium: Single known example not well enough preserved to permit detailed comparison with other species, but resembles *P. granulatum;* axis appears to be a little longer and a little less constricted in its anterior third.

*Observations.*—This species is known only from three cephala, two of them fragmentary, and a single poorly preserved pygidium. It appears to be specifically distinct from *P. granulatum*, although close to that species.

*Types.*—Holotype, cephalon, Univ. Montpellier (Collection Thoral) no. H17. Paratypes, cephala, Univ. Montpellier (Collection Thoral) no. H18, and pygidium, no. H19. Counterpart of holotype, Princeton Univ. no. 41417.

*Age and locality.*—"Middle Acadian" beds with *Paradoxides mediterraneus* and *Solenopleura rouayrouxi*, outcropping between Favayroles and Cousse, Hérault.

### Family AGNOSTIDAE McCoy, emend. Howell

Agnostians with bilobed glabella showing more or less of a trace of a medial furrow; front of the glabella little, if at all, pointed. Pygidium with well devel-

oped axis showing at least some trace of transverse furrows; evenly rounded, not pointed, at the rear; axis may separate the pleural lobes behind; brim and flange of medium width; spines on the rear corners of the pygidium small or absent.

Genus FALLAGNOSTUS Howell, n. gen.

Cephalon with faint medial furrow; glabella not drawn out into a point in front. Surface of both shields smooth. Axis of pygidium pouch-shaped; widest, broadly and bluntly rounded at its rear end; no spines on the flange; brim and flange of moderate width. Genotype and only known species, *F. blayaci.*

FALLAGNOSTUS BLAYACI Howell, n. sp.
Plate 23, figures 1, 2

Cephalon: Anterior lobe of glabella small; transverse furrow faint. Whole shield of medium convexity.

Thorax: Unknown.

Pygidium: Axis almost parallel-sided, except for a slight expansion at rear end; tubercle elongate; anterior dorsal furrow alone developed.

*Observations.*—This species would seem to be a Middle Cambrian member of a group of agnostians that in North America in Late Cambrian times included a number of species different enough from the present one to deserve assignment to an independent genus, yet resembling it in a general way. No other Middle Cambrian species of this sort are known to the writer.

*Types.*—Holotype, pygidium, Univ. Montpellier (Collection Thoral) no. H20. Paratypes, cephala, same collection, no. H21; cephalon, Princeton Univ. no. 41174b. Counterpart of holotype, Princeton Univ. no. 41174a.

*Age and locality.*—Late "middle Acadian" (Paradoxidian) of Champ du Travers 3ème Ravine, of Thoral, at Coulouma.

DISCUSSION

The eight species described above are of peculiar interest because of the geographical position of the region in which they occur and the relationships which they show to certain agnostians in other parts of the world. *Peronopsis miqueli*, *P. sallesi*, *Condylopyge imperator*, and *Pleuroctenium magnificum* are comparable with species found elsewhere; but the other four species are remarkable in various ways. *Phalacroma thorali* appears to be a forerunner of the late Paradoxidian species of *Grandagnostus*, and serves to connect that genus with *Phalacroma*. *Platagnostus immensus* is many times as large as the only other known species of its genus, *P. bibullatus*. *Gallagnostus geminus* has no known close relatives in Europe or North America, but has two in South America. *Fallagnostus blayaci* is the only known Middle Cambrian representative of its group, its nearest relatives being apparently Upper Cambrian species found in North America. These species indicate that future discoveries of Middle Cambrian agnostians in the Mediterranean region will throw important new light on various problems of agnostian evolution and migration.

## III. AGNOSTIAN TRILOBITES FROM THE TREMADOCIAN AND ARENIGIAN (LOWER ORDOVICIAN) BEDS

The Tremadocian beds of the Montagne Noire region and their fossils have been discussed in a number of publications.[10] The Tremado-

[10] See works cited in footnote 7, and Pompeckj, F. J., Aus dem Tremadoc der Montagne

cian faunas of the Monts de Lacaune have been discovered only recently. Thoral, who first found them, has published a preliminary note concerning them,[11] and will publish a fuller description soon.

Of the specimens described below, two forms came from middle Tremadocian shales, one from upper Tremadocian shales, and eight from lower Arenigian shales. Most of the specimens were collected by M. Jean Miquel.

## Family GERAGNOSTIDAE Howell, n. fam.

Agnostians with the transverse furrow of the glabella very faint, with no medial furrow, but with spines on the pygidium, a short, trilobed axis, and a smooth test. It is Tremadocian and Medial Ordovician in age. Only known genus, *Geragnostus*.

### Genus GERAGNOSTUS Howell, n. gen.

The characters of the genus are those of the family. Genotype, *Agnostus sidenbladhi* Linnarsson.

#### GERAGNOSTUS SIDENBLADHI (Linnarsson) var. GALLICUS Howell, n. var.
Plate 23, figure 3

Single, imperfectly preserved pygidium; axis well preserved; flange so poorly shown that no spines can be distinguished though probably present. Variety differs from species in that the transverse furrows on the axis run less directly across, and in the wider flange.

*Observations.*—Distortion of the holotype makes its exact proportions uncertain, and it is possible that the specimen should be referred directly to *G. sidenbladhi*. As far as the writer can determine, however, this pygidium deserves recognition as a variety. The species was originally described from Sweden and has since been recorded from England.

This variety is probably the form which was referred to by Miquel[12] and by Blayac and Daguin[13] as *Agnostus sidenbladhi*.

*Type.*—Holotype, Univ. Montpellier (Collection Miquel) no. H42.

*Age and locality.*—Middle Tremadocian dark-gray shale, Les Combes de Barroubio, Hérault.

#### GERAGNOSTUS OCCITANUS Howell, n. sp.
Plate 23, figures 4, 5

Only three cephala known; glabella relatively large, triangular; showing only the merest trace of a transverse furrow, though with slight indentations in the sides of the glabella opposite the tubercle; tubercle well developed; basal lobes small, but distinct.

*Observations.*—Without the pygidium the relationship of this species to others of the genus remains uncertain.

*Types.*—Holotype, Univ. Montpellier (Collection Miquel) no. H43; cast, Princeton Univ. no. 41175, U. S. Nat. Museum. Paratypes, Univ. Montpellier nos. H44, H45; cast of no. H44, Princeton Univ., no. 41176.

*Age and locality.*—The holotype is from the early Arenigian dark-gray shale of Barroubio, Hérault. The paratypes are from an Arenigian bed of similar shale, probably earliest Arenigian, though the stage is not specified on the original label, near St. Chinian.

#### GERAGNOSTUS CALLAVEI (Raw) var. MEDITERRANEUS Howell, n. var.
Plate 23, figures 6, 7

Cephalon: Whole shield of medium convexity, with well developed furrows; transverse furrow arched forward. Main lobe of glabella indented one-third of

Noire (Süd-Frankreich): *Neues Jahrb. Min. Geol. Palaeont.*, Jahrg. 1902, Bd. 1, pp. 1–8.

[11] Thoral, Marcel, Nouvelle contribution à la stratigraphie du cambrien et du silurien de la partie orientale des Monts de Lacaune: *Acad. Sci. Paris, Comptes rend.*, vol. 194, pp. 1671–1673, 1932.

[12] Miquel, 1912, *op. cit.*, p. 17.

[13] Blayac and Daguin, 1922, *op. cit.*, p. 5.

the way back; basal lobes large, almost confluent; brim wide; tubercle at the anterior end of the main lobe of the glabella.

Thorax: Unknown.

Pygidium: Whole shield of medium convexity, with well developed furrows; flange broad; spines of medium size. Front two-fifths of axis divided into two lobes of about equal size, crossed by a prominent, elongate, tubercle.

*Observations.*—The cephalon and pygidium of this agnostian so much resemble those of *Geragnostus callavei* in shape and size that it may be looked upon as a variety of that English species. It differs from *callavei* (if the figure of that species published by Lake is correct) in having the transverse furrow of the glabella more strongly developed, larger spines on the flange, and a deeper transverse furrow separating the middle segment of the axis of the pygidium from the posterior segment.

*Types.*—Holotype, pygidium, Univ. Montpellier no. H47. Paratypes, three cephala and a pygidium, same collection, nos. H46, H48, H49. Casts of holotype and a paratype cephalon, Princeton Univ. nos. 41231, 41232.

*Age and locality.*—Early Arenigian dark-gray shale of Les Combes de Barroubio, Hérault; and hard gray shale of the vicinity of St. Chinian, Hérault (holotype).

GERAGNOSTUS PUSIO Howell, n. sp.

Plate 23, figure 8

Only the pygidium known; small (2 mm. long), highly convex; strong dorsal and transverse furrows. Prominent keel on the axis rising into a tubercle near its rear end; flange rather wide, convex, bearing small, but distinct, spines. Rear segment of axis somewhat expanded in its middle portion, so that its widest part is wider than the widest part of the middle segment, though not wider than the anterior segment. Test smooth.

*Observations.*—The little pygidium on which this species is based may be a young shield of one of the early Arenigian species, *Geragnostus occitanus* or *G. callavei mediterraneus*. It is much smaller than the known pygidia of *G. callevei mediterraneus*. The pygidium of *G. occitanus* is unknown, but the known cephala are much larger than the holotype of *pusio*. If the pygidium on which *G. pusio* is based is that of an adult individual, *pusio* is the smallest known species of the genus, and one of the smallest of all trilobites.

*Types.*—Holotype, Univ. Montpellier (Collection Villebrun) no. H50; cast, Princeton Univ. no. 41420.

*Age and locality.*—Early Arenigian (Early Ordovician), near St. Chinian, Hérault.

GERAGNOSTUS AMBIGUUS Howell, n. sp.

Plate 23, figure 9

*Agnostus* sp. THORAL, *1932*, Nouvelle contribution à la stratigraphie du Cambrien et du Silurien de la partie orientale des Monts de Lacaune: *Acad. Sci. (Paris), Comptes rend.*, vol. 194, p. 1672.

Only a single imperfect pygidium known; convexity moderate; test smooth; dorsal furrow well developed, but not deep; flange normal, bearing small, but distinct, spines; axis too imperfect for description.

*Observations.*—The pygidium on which this species is based may be that of young *G. callavei mediterraneus*, for it agrees, as far as can be determined from such an imperfectly preserved specimen, with that species in form. It is, however, only half as large as the known pygidia of *G. callavei mediterraneus* and differs from them in having a narrower flange. It therefore seems probable that it is a distinct species.

*Type.*—Holotype, Univ. Montpellier (Collection Thoral) no. H51; cast, Princeton Univ. no. 41421, U. S. Nat. Museum.

*Age and locality.*—Late Tremadocian, Early Ordovician, Chemin de la Barthe, south of Canac, Monts de Lacaune.

## Family MICRAGNOSTIDAE Howell, n. fam.

Agnostia with clearly bilobed glabella, tapering forward, but evenly rounded in front; no medial furrow. Short pygidial axis surrounded by a deep dorsal groove and divided into segments. Most of the species small, even for agnostians. Range, Late Cambrian to Tremadocian. The two genera now placed in it, *Micragnostus* and *Anglagnostus*, are defined below. The family is closely related to the Geragnostidae, to which it may be ancestral, and with which it should perhaps be merged, although there is not sufficient evidence to justify such action at this time.

### Genus MICRAGNOSTUS Howell, n. gen.

Glabella strongly outlined by the dorsal furrow; axis of pygidium strongly convex, more than half as long as the whole pygidium, clearly trilobate. Genotype, *Agnostus calvus* Lake. *A. calvus latemarginalis* Stubblefield and Bulman, *A. bisectus* Matthew, and *A. insuetus* Raymond are also placed in the genus.

#### MICRAGNOSTUS LANGUEDOCENSIS Howell, n. sp. Plate 23, figure 10

Single known pygidium so poorly preserved that nothing can be determined about the axis except outline. Because of its very small size (2.5 mm. long), and the resemblance of those portions which are preserved to the corresponding portions of other species of *Micragnostus*, it is thought to belong in that genus. Shield appears to have been highly convex; axis elevated well above the pleural lobes; flange of moderate width, bearing a small spine on each rear corner.

*Observations.*—Imperfect preservation makes comparisons difficult, but as far as the writer has been able to determine, it differs enough in its proportions from those of the other known species of *Micragnostus* to deserve a distinct specific name.

*Type.*—Holotype, Univ. Montpellier (Collection Villebrun) no. H52; cast, Princeton Univ., no. 41177, U. S. Nat. Mus.

*Age and locality.*—Early Arenigian dark-gray shale near St. Chinian.

### Genus ANGLAGNOSTUS Howell, n. gen.

Glabella shorter and less strongly developed than in *Micragnostus;* axis of pygidium shorter than in that genus (only half as long as the whole pygidium); not strongly trilobed. Genotype, *Agnostus dux* Callaway.

#### ANGLAGNOSTUS BARROUBIOENSIS Howell, n. sp. Plate 23, figure 11

Cephalon with broad brim; glabella distinctly bilobed; small, only one-half the length of the whole shield; narrow; anterior lobe very small.

*Observations.*—The single cephalon on which this species is based occurs in the same sort of middle Tremadocian dark-gray shale as that in which the pygidium chosen as the holotype of *Geragnostus sidenbladhi gallicus* is preserved, and is of about the same size. It is possible that the two are referable to a single species of *Anglagnostus*. At present the evidence appears to be against this possibility, since the pygidium in question resembles that of *G. sidenbladhi*. It is so imperfectly preserved, however, and so much distorted, that its true form, and therefore its relationships, must remain in doubt until better specimens are discovered.

*Type.*—Holotype, cephalon, Univ. Montpellier no. H53.

*Age and locality.*—Middle Tremadocian dark-gray shale of Barroubio, Hérault.

## Family TRINODIDAE Howell, n. fam.

Agnostians with ovoid, one-lobed, glabella, or the rear part of such a glabella (the front part not being defined by the dorsal furrow); pygidium with

very short, but lobed, axis, or the anterior part of such an axis (the rear part not being defined by the dorsal furrow). Glabella sometimes with faint traces of a transverse furrow, but never truly bilobed. Age Ordovician. Type genus, *Trinodus*, the most important of the family; others undescribed.

### Genus TRINODUS M'Coy

Glabella defined all the way around the front by the dorsal furrow. Axis of pygidium short, defined all the way around by the dorsal furrow. No clear trace of transverse furrow on the glabella. Surface of both shields smooth. Genotype, *T. agnostiformis* M'Coy. Other species referred to the genus are *Metagnostus erraticus* Jaekel, *Agnostus galba* (Billings), *A. glabratus* Angelin, *A. lentiformis* Angelin, *A. tardus* (Barrande), *A. bavaricus* Barrande, *A. trinodus* Salter, and *Arthrorhachis longicollis* Raymond

*Arthrorhachis* Corda and a part of *Metagnostus* Jaekel are included in this genus, as here defined.

#### TRINODUS CHINIANENSIS Howell, n. sp.
Plate 23, figures 12, 13

Cephalon: Well developed tubercle on middle of upper surface of glabella; brim a little more than medium in width; no clearly discernible trace of transverse furrow on glabella. Whole shield of medium convexity; test smooth.

Thorax: Unknown.

Pygidium: Only known example lacks anterior portion. Axis short, tapering; two segments preserved, anterior bearing tubercle; tiny tubercle, projecting backward, on posterior extremity of axis. Whole pygidium highly convex (more so than the cephalon); axis not rising much above the general upper level of the shield; flange of somewhat more than medium width, without spines, as far as can be determined from the one known specimen. Surface of both shields smooth.

*Observations.*—It seems probable that the cephalon and pygidium described above belong to a single species, because the known examples of both shields are of about the same size, occur in the same sort of rock, and come from the same locality. As the exact form of the axis of the pygidium is not known, it is impossible to make accurate comparisons. As far as can be determined, *Trinodus chinianensis* is close to *T. tardus* (Barrande), of Bohemia, but differs in having the backward projecting tubercle at the rear extremity of the axis of the pygidium, and possibly in other respects. It differs from *T. bavaricus* (Barrande), of Bavaria, in being relatively wider in proportion to its length.

*Types.*—Holotype, cephalon, Univ. Montpellier (Collection Villebrun) no. H54. Paratypes, cephalon and pygidium, same collection, nos. H55, H56. Casts, holotype and paratype pygidium, Princeton Univ. nos. 41178, 41179; U. S. Nat. Museum.

*Age and locality.*—Hard, black early Arenigian shale near St. Chinian, Hérault.

#### TRINODUS CORPULENTUS Howell, n. sp.
Plate 23, figure 14

Single pygidium of small size (2 mm. long) and considerable convexity. Axis bluntly triangular, highly convex, crossed by two deep transverse furrows; prominent keel on middle segment. Pleural portion of the shield very bulbous; rear portion sloping very steeply to the level of the flange; flange convex, of medium width, armed with small, but distinct, spines. Surface not well preserved; nearly smooth, but showing traces of what may have been small tubercles.

*Observations.*—The pygidium on which this species is based, if adult (and there is no evidence that it is not), is remarkable for its small size and unusual globosity. It may be a young pygidium of one of the other species of *Trinodus* here described, but, in the absence of any proof of the fact, it seems best to view it as a new species. It differs from the pygidium of *T. chinianensis* in having spines on the flange and in some details of shape. If the traces of tubercles on

the test are, in fact, the remains of pustules, this species is comparable in that respect with the Bohemian trinodid that Novak described as *Agnostus dusli*.

*Type.*—Holotype, Univ. Montpellier (Collection Azais) no. H57; cast, Princeton Univ. no. 41419.

*Age and locality.*—Early Arenigian near St. Chinian, Hérault.

TRINODUS ABRUPTUS Howell, n. sp.

Plate 23, figure 15

Two cephala known; glabella relatively short; anterior end of the main lobe truncated, cut nearly straight across, almost rectangular in form; glabella only half as long as the whole cephalon; tubercle on middle of upper surface of main lobe; brim rather narrow; surface smooth.

*Observations.*—This species is peculiar in having the front end of the glabella truncated, instead of rounded, as usual in *Trinodus*. The writer knows of no other species with the glabella so truncated, although in some it is just as short as in *T. abruptus*. This truncated form is probably a primitive character.

*Types.*—Holotype, Univ. Montpellier (Collection Villebrun) no. H58; cast, Princeton Univ. no. 41422, U. S. Nat. Museum. Paratype, Univ. Montpellier (Collection Villebrun) no. H59.

*Age and locality.*—Early Arenigian near St. Chinian, Hérault.

TRINODUS OVIFORMIS Howell, n. sp.

Plate 23, figure 16

Single cephalon known; rather highly convex for *Trinodus;* dorsal furrow strongly developed; glabella rising well above the level of the cheeks; tubercle on middle of upper surface of main lobe of glabella; brim of moderate width; surface smooth.

*Observations.*—The cephalon of this species resembles in general form that of *Trinodus chinianensis*, which occurs with it, but is much more convex. In *T. chinianensis* the glabella scarcely rises above the level of the cheeks and the dorsal furrow is faint, while in *T. oviformis* the opposite is true. The pygidium assigned to *T. chinianensis* may belong to *T. oviformis*, but as *T. chinianensis* is, if we may judge from the number of its cephala which have been found, the commoner species of the two, it seems probable that the one known *Trinodus* pygidium is referable to that species.

*Type.*—Holotype, Univ. Montpellier no. H60; cast, Princeton Univ. no. 41423, U. S. Nat. Museum.

*Age and locality.*—Early Arenigian near St. Chinian, Hérault.

DISCUSSION

The 11 species of agnostians described above are a typical Early Ordovician assemblage, such as one would expect to find in beds known to contain the other trilobites previously recorded from the Tremadocian exposures of southern France, although the presence of so many species of *Trinodus* is somewhat remarkable in beds as old as these. It is hoped that future collecting will add to our knowledge of these species which are now so imperfectly known from the few specimens that are available for study.

## IV. AGNOSTIAN TRILOBITES FROM THE ARENIGIAN (LOWER ORDOVICIAN) CALYMENE SHALES

The *Calymene* shales of Hérault until recently have been considered by French stratigraphers to be of Medial Ordovician (Llandeilian) age,[14] but are now known to be of Arenigian (Early Ordovician) age. Only one agnostian has previously

[14] See papers cited in footnote 7.

been recorded from these beds, as *Agnostus tardus*,[15] but it is here referred to a new species.

## Family LEIAGNOSTIDAE Jaekel, emend. Howell

### Genus LEIAGNOSTUS Jaekel

Jaekel[16] took his species *Leiagnostus erraticus* as the genotype of his genus *Leiagnostus*, but he also placed in the genus *Agnostus nudus* (Beyrich), *A. n.* var. *scanicus* Tullberg, and *A. glandiformis* Angelin. The writer would exclude these Cambrian species, and would place in the genus only those Ordovician species with smooth cephala and smooth pygidia with a rather wide flange. The only species that he would assign to the genus at this time are *L. erraticus*, *L. bohemicus* (Novák), and the new species *L. foulonensis*, described below.

[15] Miquel, *op. cit.*, p. 25.

[16] Jaekel, O., Uber die Agnostiden: *Deutsche Geol. Gesell, Zeitschr.*, vol. 61, pp. 380–401, 1909.

#### LEIAGNOSTUS FOULONENSIS Howell, n. sp.
Plate 23, figures 17, 18

Cephalon: Smooth, evenly rounded; convexity medium; brim narrow. No trace of a glabella; none of the few known examples show any evidence of a tubercle on their upper surfaces.

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EXPLANATION OF PLATE 23

FIGS. 1–2—*Fallagnostus blayaci* Howell, n. gen. and sp. 1, Holotype pygidium, ×6 (Thoral Coll. no. H20). 2, Paratype cephalon, ×5 (Thoral Coll. no. H21). (p. 230)

3—*Geragnostus sidenbladhi* (Linnarsson) var. *gallicus* Howell, n. gen. and var., holotype pygidium, ×5 (Miquel Coll. no. H42). (p. 231)

4–5—*Geragnostus occitanus* Howell, n. gen. and sp. 4, Holotype cephalon, ×5 (Miquel Coll. no. H43). 5, Paratype cephalon, ×5 (Univ. Montpellier no. H44). (p. 231)

6–7—*Geragnostus callavei* (Raw) var. *mediterraneus* Howell, n. gen. and var. 6, Paratype cephalon, ×5 (Univ. Montpellier no. H46). 7, Holotype pygidium, ×5 (Villebrun Coll., Univ. Montpellier no. H47). (p. 231)

8—*Geragnostus pusio* Howell, n. gen. and sp., holotype pygidium, ×6 (Villebrun Coll., Univ. Montpellier no. H50). (p. 232)

9—*Geragnostus ambiguus* Howell, n. gen. and sp., holotype pygidium, ×5 (Thoral Coll. no. H51). (p. 232)

10—*Micragnostus languedocensis* Howell, n. gen. and sp., holotype pygidium, ×5 (Villebrun Coll., Univ. Montpellier no. H52). (p. 233)

11—*Anglagnostus barroubioensis* Howell, n. gen. and sp., holotype cephalon, ×5 (Univ. Montpellier no. H53). (p. 233)

12–13—*Trinodus chinianensis* Howell, n. sp. 12, Holotype cephalon, ×5 (Villebrun Coll., Univ. Montpellier no. H54). 13, Paratype pygidium, ×5 (Azais Coll., Univ. Montpellier no. H56). (p. 234)

14—*Trinodus corpulentus* Howell, n. sp., holotype pygidium, ×6 (Azais Coll., Univ. Montpellier no. H57). (p. 234)

15—*Trinodus abruptus* Howell, n. sp., holotype cephalon, ×5 (Villebrun Coll., Univ. Montpellier no. H58). (p. 235)

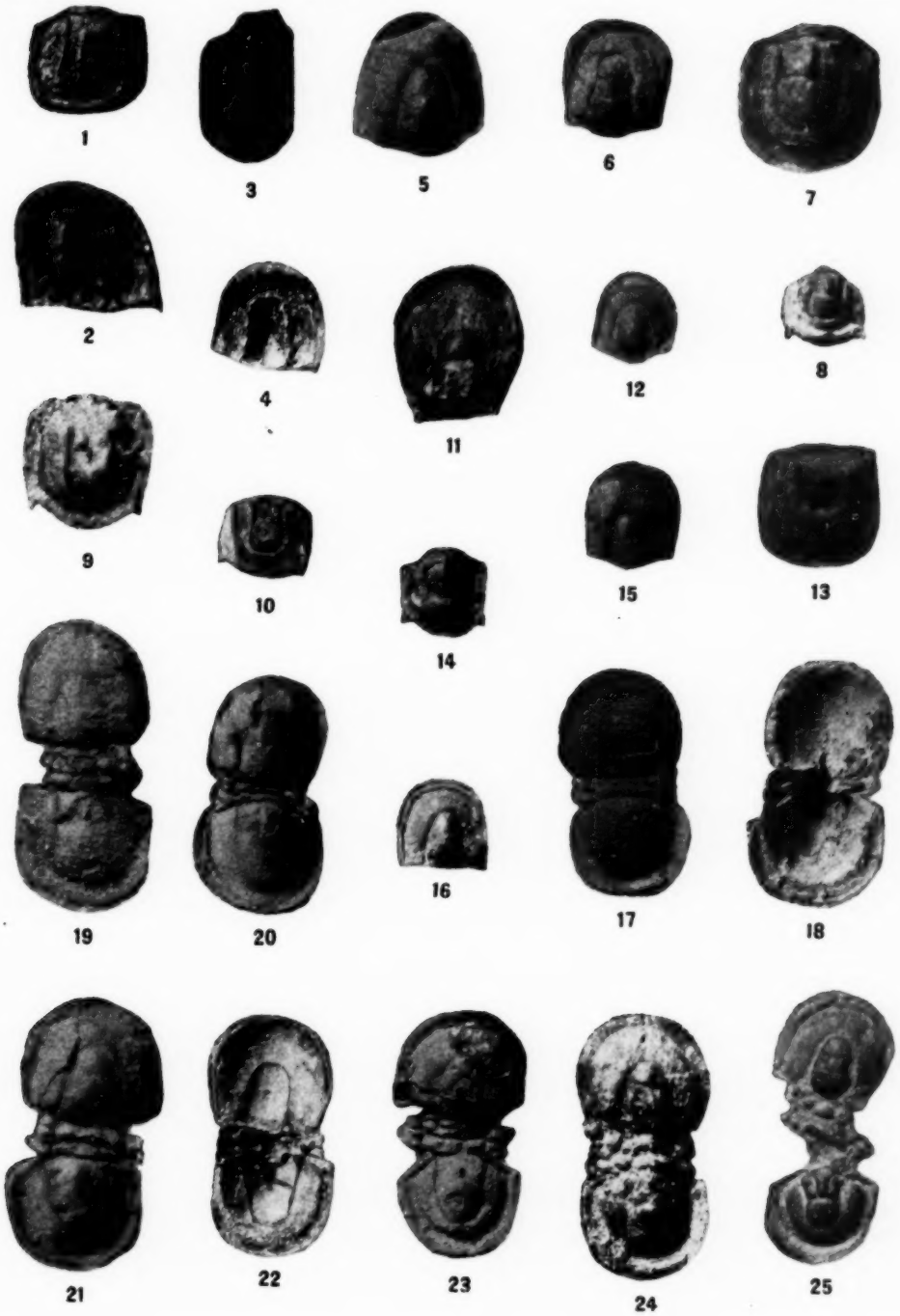
16—*Trinodus oviformis* Howell, n. sp., holotype cephalon, ×5 (Villebrun Coll., Univ. Montpellier no. H60). (p. 235)

17–18—*Leiagnostus foulonensis* Howell, n. sp. 17, Holotype, entire test, ×5 (Univ. Montpellier no. H61a1). 18, Paratype, entire test, ×5 (Univ. Montpellier no. H61a4). (p. 236)

19–21—*Geragnostus languidus* Howell, n. sp. 19, Holotype, entire test, ×4 (Univ. Montpellier no. H65a1). 20, Paratype , entire test, ×5 (Univ. Montpellier no. H66). 21, Paratype, entire test, ×5 (Univ. Montpellier no. H62b1). (p. 237)

22–23—*Geragnostus boutouryensis* Howell, n. sp. 22, Holotype, entire test, ×5 (Univ. Montpellier no. H61b3). 23, Paratype, entire test, ×5 (Univ. Montpellier no. H61b2). (p. 237)

24–25—*Geragnostus manifestus* Howell, n. sp. 24, Holotype, entire test, ×5 (Univ. Montpellier no. H69). 25, Paratype entire test, ×5 (Univ. Montepllier no. H70). (p. 238)




Howell, Cambrian and Ordovician Trilobites

Thorax: Axial portion of anterior segment with fairly well developed nodes; nodes of posterior segment not so elevated above general surface of thorax.

Pygidium: No trace of an axis; small tubercle on upper surface of shield. Shield smooth, rather highly convex, with wide flange.

*Observations.*—This species appears to differ from *Leiagnostus erraticus* in its subquadrate pygidium, a well developed tubercle on the pygidium, a wider flange, and nodes on the axis of the thorax. *L. erraticus* is known only from a glacial boulder found in northern Germany and thought to have come from the *Echinosphaerites* limestone of the Baltic region, a formation considered to be of Medial Ordovician age.

*L. foulonensis* differs from *L. bohemicus* (Novák) in its more quadrate pygidium, wider flange, and nodes on the axis of the thorax. *L. bohemicus* is found in Zone $Dd_1\gamma$ (Lower Ordovician) of Bohemia; its cephalon is unknown.

*Types.*—Holotype, entire test, Univ. Montpellier no. H61a1. Paratypes, same collection, nos. H61a4, H61a5, H62c, H63, H64a. Cast of holotype, Princeton Univ. no. 41180, U. S. Nat. Museum.

*Age and locality.*—Gray shale of the *Calymene* shales of Le Foulon and Boutoury, Hérault.

## Family GERAGNOSTIDAE Howell[17]

### Genus GERAGNOSTUS Howell

#### GERAGNOSTUS LANGUIDUS Howell, n. sp.

Plate 23, figures 19–21

Cephalon: Dorsal furrow faint, especially in front; glabella not rising above the general level of the cephalon; basal lobes small; brim of medium width. Whole shield smooth, of medium convexity.

Thorax: Nodes on axis of thorax well developed, especially on anterior segment.

Pygidium: Whole shield rather highly convex; dorsal and transverse furrows faint, but discernible; axis clearly trilobed; well developed tubercle on second segment of axis; anterior transverse furrow bowed forward near tubercle and almost parallel to the long axis of the shield; second segment indented beside the tubercle and parallel to the long axis of the shield, with indentations in line with parts of anterior transverse furrow so that there appear to be two parallel furrows running lengthwise of the axis over its first and second segments; tiny tubercle at posterior extremity of axis. Whole shield rather highly convex; axis not rising appreciably above the general level of the surface. Test smooth; flange wide, without spines.

*Observations.*—Of the species of *Geragnostus* found in the *Calymene* shales of Hérault, this one has the dorsal furrow least developed and the glabella and the axis of the pygidium least prominent.

*Types.*—Holotype, entire test, Univ. Montpellier no. H65a1. Paratypes, same collection, nos. H62b1, H62b6, H62b7, H65a2, H65a3, H66, H67. Cast of holotype, Princeton Univ. no. 41181, U. S. Nat. Museum.

*Age and locality.*—Gray shale of the Middle Ordovician *Calymene* shales of Boutoury and Le Foulon, Hérault.

#### GERAGNOSTUS BOUTOURYENSIS Howell, n. sp.

Plate 23, figures 22, 23

Cephalon: Glabella clearly defined by dorsal furrow, rising a little above the general level of the shield (which is of medium convexity), and bearing a distinct tubercle; only the faintest trace of transverse furrow running directly across the middle of the glabella; extremities of furrow not clearly distinguished, although faint indications extend diagonally forward from the transverse portion; Basal lobes small; brim rather wide; test smooth.

Thorax: Nodes well developed on axial portions of both segments.

Pygidium: Axis clearly defined; dorsal furrow shallow. Axis rising above general

[17] See page 231.

level of shield; shield, as a whole, rather highly convex; very prominent tubercle on second segment of axis; transverse furrows faint; axis clearly three-lobed; flange wide, without spines. Surface smooth.

*Observations.*—This species is intermediate between *Geragnostus languidus* and *G. manifestus* (described below), in the prominence of the glabella and the axis of the pygidium. The axis of the pygidium is also a little longer and narrower than that of *G. languidus*.

*Types.*—Holotype, an entire test, Univ. Montpellier no. H61b3. Paratypes, same collection, nos. H64b, H65b, H68. Cast of holotype, Princeton Univ. no. 41182, U. S. Nat. Museum.

*Age and locality.*—Gray shale of the *Calymene* shales of Le Foulon and Boutoury, Hérault.

GERAGNOSTUS MANIFESTUS Howell, n. sp.
Plate 23, figures 24, 25

Cephalon: Dorsal furrow well developed; glabella prominent, rising well above the general level of the shield; shield of more than medium convexity; small tubercle on glabella; transverse furrow faint, bow-shaped, with the point of the arc just in front of the tubercle: basal lobes small; test smooth.

Thorax: Nodes very strongly developed on axial portions of both segments.

Pygidium: Whole shield highly convex; axis, though narrow and rather short, strongly set off by a deep dorsal furrow, rising well above the general level of the whole shield; transverse furrows very deep, dividing axis into 3 distinct lobes; long, prominent tubercle crossing the two anterior segments of axis; near tubercle, parallel to the long axis of the pygidium, two deep furrows, with anterior portions formed by forward-bending anterior transverse furrow; surface smooth; flange wide, without spines.

*Observations.*—This species is distinguished by its prominent glabella and very prominent pygidial axis, whose transverse furrows are also notable, and by the width of the flange on its pygidium.

*Types.*—Holotype, entire test, Univ. Montpellier no. H69. Paratype, entire test, same collection, no H70. Casts of both, Princeton Univ. nos. 41183, 41184; U. S. Nat. Museum.

*Age and locality.*—The holotype is from gray shale of the Arenigian *Calymene* shales of Boutoury, Hérault. The paratype is from similar shale from Hérault; the original label does not state the horizon or exact locality.

JOURNAL OF PALEONTOLOGY, VOL. 9, NO. 3, PP. 239–246, PL. 24, APRIL, 1935

# A NEW ORDOVICIAN GRAPTOLITE LOCALITY IN UTAH[1]

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ABSTRACT

Few graptolites have been recorded from the Cordilleran region. In the Ordovician Garden City and Swan Peak formations near Logan, Utah, several localities yield numerous graptolites associated with other fossils. The faunas from these localities are listed and some stratigraphic data are given. Two brachiopods, a cephalopod, two trilobites, and a phyllocarid are new.

Some years ago Dr. R. V. Chamberlain, one of the curators in the Museum of Comparative Zoology, Cambridge, Massachusetts, presented that museum with a small collection of graptolites from Logan, Utah. At that time graptolites from the Cordilleran region were rarities; not more than half a dozen localities where they might be obtained had been recorded. Fortunately, others have since come to light, and we are probably on the way toward a far better understanding of the distribution of graptolites than has heretofore been possible. As far as I can discover, graptolites have never been reported from Logan. In 1924 I was able to visit the region and to supplement Doctor Chamberlain's collection.

My thanks are due to Professor William Peterson, Director of the State Agricultural College, who very kindly guided me to localities that would otherwise have been difficult to find, and also to the Director of the Museum of Comparative Zoology for the loan of Doctor Chamberlain's material. I also wish to express my thanks to Dr. F. E. Lloyd, of McGill University for his generous assistance in the work of taking the photographs used in the plate accompanying this paper.

[1] Manuscript received July 1, 1933.

## THE LOCALITIES

It appears that graptolites are not uncommon in the Ordovician rocks in the vicinity of Logan, but limited time permitted me to visit only two localities, Logan Canyon, and a small hill about 1 mile south of Mount Pisgah, in the southwestern part of the Logan (Utah-Idaho) quadrangle, about 15 miles south-southwest of Logan. At neither of these places do the graptolites occur in black shales. In Logan Canyon they are contained in limestone and calcareous shales (Garden City formation), and at the locality south of Mount Pisgah for the most part in non-calcareous extremely fine-grained shales (Swan Peak formation).[2] This fine-grained shale locality is of especial importance because of the wealth of other fossils associated with the graptolites,

[2] I am indebted to Dr. Edwin Kirk for the identification of the formations whence these collections were made.

such as brachiopods, cephalopods, trilobites, ostracodes, and phyllocarids, including six new species and at least one new genus. The horizons indicated by the graptolites seem to be the Deep Kill zone of Beekmantown (Canadian) age, the characteristic species being *Didymograptus nitidus* and *D. bifidus*. The collections are too small to indicate the accepted difference in age between the Garden City and Swan Peak formations. In the shales of the Garden City in Logan Canyon dendroid graptolites are the most common, but associated with them are at least two species of *Didymograptus*. A very remarkable thing about the state of preservation of the graptolites in the canyon is that the dendroid species are preserved with great perfection of detail, and with little distortion, whereas the others are for the most part scarcely recognizable, and usually fragmentary.

*Logan Canyon.*—The canyon, which trends approximately east, has been excavated across the strike of a broad synclinal fold of Paleozoic strata, which, near the mouth of the canyon, dip gently eastwards. The lowest beds exposed in the canyon, those forming the wall of the Cache Valley from this point southwards to Blacksmith Fork, are of Cambrian age.[3] These are succeeded by the Garden City formation, of Beekmantown age, bearing graptolites, which in turn is covered by the Swan Peak, the Upper Ordovician Fish Haven dolomite, the Silurian Laketown dolomite, and younger Paleozoic strata. The localities from which collections were made, all on the south wall of the Canyon and in the Garden City formation, are as follows:

A. Shoulder of cliff just opposite Power Station, near entrance of canyon. Ten feet feet above road.
   *Bellefontia chamberlaini* Clark, n. sp.

B. About 200 feet above road at a point midway between localities A and C.
   *Didymograptus* cf. *D. bifidus* (Hall)
   *Lingulella* sp. indet.
   Small trilobites, indeterminate fragments

C. 20 feet above road at the pole marked 200.
   *Dictyonema rectilineatum* Ruedemann
   *Desmograptus intricatus* Ruedemann
   *Periglyptocrinus* sp.

D. Talus from cliffs of dry gully nearly opposite Power House.
   *Dictyonema* sp.

E. Dr. Chamberlain's collection, exact locality unknown.
   *Clonograptus flexilis* (Hall)
   Dendroid graptolites, several unidentified species

Stratigraphically, locality A is the lowest, followed by locality B. Localities C and D are higher and probably from the same horizon. That these collections are very incomplete it is needless to point out. In a series of calcareous strata it is exceptional to get a good succession of graptolite faunas, and yet these limestones are, singularly, almost devoid of other fossils. The presence of *Periglyptocrinus* is remarkable, no member of its family having been reported, as far as I am aware, from rocks older than the Trenton.

*Hill near Mount Pisgah.*—South of Mount Pisgah is a group of small

[3] Walcott, C. D., Cambrian geology and paleontology: *Smithson. Misc. Coll.*, vol. 53, p. 190, 1908.

hills, a hundred feet or so high, one of which is capped by Lower Ordovician strata, probably uppermost beds of the Garden City formation, limestones which carry no fossils except a small gastropod probably belonging to *Ophileta*, or a related genus. Below these on the flank of the hill, but overlying them stratigraphically, are a few feet of arenaceous shales and limestones belonging to the Swan Peak formation and containing brachiopods and graptolites, each represented by one species only; and half way down the hill, the uppermost bed is well exposed. This is an extremely fine-grained shale, buff to olive-drab in color, and is crowded with graptolites, brachiopods, trilobites, ostracodes, phyllocarids, and cephalopods. It is remarkable that in each of the two graptolite-bearing zones on this hill there should be but one species preserved. In the lower horizon *Didymograptus extensus* occurs sparingly, and *D. bifidus* is exceedingly abundant in the upper bed. This is the order of occurrence reported by Ruedemann at Deep Kill, N.Y., although the writer has not found it to be characteristic of the graptolite succession at Lévis, Quebec. The localities from which fossils were collected on this hill are as follows:

F. Summit of hillock, limestone at stratigraphic base of series, probably Garden City formation.
   *Ophileta* (?) sp. indet.

G. Arenaceous limestones and shales immediately above beds of station F. Swan Peak formation.
   *Didymograptus nitidus* (Hall)
   *Orthis michaelis* Clark, n. sp.
   *Protocycloceras debilis* Clark, n. sp.

H. Fine-grained shales on slopes of hillock, at the top of series. Swan Peak formation.
   *Didymograptus bifidus* (Hall) (Pl. 24, fig. 2.)
   *Lingulella cf. pogonipensis* (Walcott)
   *L. bellisculpta* Clark, n. sp.
   *Orthis michaelis* Clark, n. sp.
   *Protocycloceras debilis* Clark, n. sp.
   *Eleutherocentrus petersoni* Clark, n. gen. and sp.
   Ostracodes
   *Tuzoia subtile* Clark, n. sp.

## DESCRIPTION OF SPECIES[4]

### GRAPTOLITOIDEA

#### CLONOGRAPTUS FLEXILIS (Hall)
Plate 24, figure 1

HALL, J., *1865*, Canadian Organic Remains, dec. 2, p. 103, pl. 10, figs. 3–9.

In Doctor Chamberlain's collection one specimen of *Clonograptus* with branches crushed flat gives a false impression of coarseness. In specimens of this genus from Lévis, Quebec, the branches invariably preserve their circular cross-section, and appear as thin subcylindrical rods. The specimen in question differs in no other way from specimens of *C. flexilis* from the type locality, except in a certain compactness of form achieved by a tendency of the dichotomies to be concentrated near the center. no theca can be seen, although there are several branches of the sixth order. It is the only fossil on its slab of limestone.

Loc. E, Garden City formation, Logan Canyon, Utah.

### CRINOIDEA

#### PERIGLYPTOCRINUS sp.

*Periglyptocrinus* WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata:

[4] With one exception, the type specimens of all the species hereafter described are in the collections of the Peter Redpath Museum, McGill University, Montreal. See explanations of plates for type numbers.

Mus. Comp. Zool., Mem., vol. 20, pt. 1, p. 277.

In the only specimen collected the calyx was crushed, and the arms had been displaced so as to lie alongside it. The radial, basal, and other plates were scarcely distinguishable. Each of the plates near the lower part of the calyx was ornamented with a six-rayed pattern of very coarse raised ridges, each ridge continuous across the suture and on to the neighboring plate, where it formed part of the pattern of that plate. The basal plates appeared to be free from such ornamentation, as did some of the plates distant from the basals, but this condition may have been due to the removal of preëxisting ridges by weathering. The arms were peculiar in branching so as to result in eighty terminal branches Such repeated dichotomy is unusual in the family Melocrinidae. *Glyptocrinus ramulosus* Billings possesses arms with forty terminal branches, but only one the calyx. *P. billingsi* Wachsmuth and Springer possesses forty terminal branches, but there is no free dichotomy. The arms were biserial, and deeply grooved between the rows of plates. No other remains of echinoderms were observed in these strata. Unfortunately, the original specimen has been lost.

Loc. C, Garden City formation, Logan Canyon, Utah.

## BRACHIOPODA

### LINGULELLA cf. POGONIPENSIS (Walcott)

WALCOTT, C. D., *1912*, Cambrian Brachiopoda: U. S. Geol. Survey, Mon. 51, p. 525.

Our collection contains a few specimens of a thin-shelled brachiopod, whose proportions are those of this species. No internal markings are preserved.

Loc. H, Swan Peak formation, south of Mount Pisgah, Utah.

### LINGULELLA BELLISCULPTA Clark, n. sp.
Plate 24, figures 3, 4

Shells small and of characteristic ovoid form; both valves preserved in approximately equal numbers. The most remarkable feature is the surface ornamentation, the crossing of the concentric furrows which follow the course of the growth lines by fine radial furrows which go from the median line of the shell in a curving line, convex anteriorly, and meet the lateral and anterior margins approximately at right angles. The resulting pattern of prominences left by the crossing furrows resembles somewhat the ornamentation of *Iphidella*, although in that genus the pattern is one of crossing ridges rather than furrows. Length of holotype, 6.5 mm.; width, 3.2 mm.

Abundant in certain layers at locality H, Swan Peak formation, south of Mount Pisgah, Utah.

### ORTHIS (s.s.) MICHAELIS Clark, n. sp.
Plate 24, figures 5, 6

Shell of medium size, averaging 15 mm. in length, 20 mm. in width. Hinge-line of the brachial valve short. Cardinal process present, but seen only in casts of the interior that do not reveal its characteristics except extreme thinness. Crural plates short and stout. No muscle scars seen. Pedicle valve with very low area; hinge-line nearly straight, short. Both valves moderately but sub-equally convex, with 30 to 34 strong, rounded plications.

Abundant at locality G, (holotype), rare at H, both in Swan Peak formation south of Mount Pisgah, Utah.

## CEPHALOPODA

### PROTOCYCLOCERAS DEBILIS Clark, n. sp.
Plate 24, figure 7

Several specimens of an annulated cone are all crushed flat, the state of preservation leaving much in doubt. Shell thin, tapering, with strong annulations; in the holotype annulations 2.5 mm. apart where shell is 16 mm. wide, 2 mm. apart where shell is 10 mm. wide; largest specimen 16 mm. wide, the annulations 3.3 mm. apart. Both inner and outer surfaces of the shell ornamented with fine annular striae, ridges on the exterior, furrows on

the interior; striae sub-parallel, never touching each other. Index of tapering about 1 in 6 or 1 in 6½, as also in the original conical shell. No internal structures can be determined. In the holotype the interior of the shell is well shown, and the absence of septal structures indicates that the larger end of this specimen is the living chamber. However, septa would probably have been as thin and incompetent as the shell itself, and might not be observable in the specimens in their present crushed condition. No trace of the siphuncle can be seen.

Fairly common at loc. H (holotype), rare at G, both in the Swan Peak formation south of Mount Pisgah, Utah.

It is difficult to contrast these specimens with others. White described a species of annulated "*Orthoceras*" (*O. colon*, Lower Ordovician Utah),[5] but his species possess a strong shell, with a peripheral siphuncle, and lacks surface markings. Of the species of *Protocycloceras* known in eastern North America only *P. whitfieldi* Ruedemann (Beekmantown, Fort Cassin, Vermont) is described as possessing "fine encircling lines."[6] *Orthoceras priamus* Billings (Beekmantown?, New Brunswick, and Chazy, Newfoundland)[7] resembles this species in surface ornamentation.

## TRILOBITA

### ELEUTHEROCENTRUS Clark, n. gen.

An ogygiocarinid with glabella long, devoid of furrows; axial lobe of pygidium produced backwards into a spine free from the posterior margin of pygidium. *Xenostegium* Walcott is related but has a spine on the posterior margin. It is probably close to *Hemigyraspis* Raymond. Genotype, *E. petersoni* Clark, n. sp.

### ELEUTHEROCENTRUS PETERSONI Clark, n. sp.

Plate 24, figures 12–19

Cephalon and pygidium of medium size, thorax known only from dissociated segments. Cephalon nearly semicircular in shape; glabella nearly twice as long as wide, bordered by well marked dorsal furrows that are parallel or very slightly divergent forwards, broadly rounded in front, reaching almost to the anterior margin of the cephalic shield; no traces of glabellar furrows, either within or without. Eyes large, slightly in front of the middle point of the glabella, distant from the latter by three-fourths its width. Free-cheeks always found detached, nearly flat, ending in a long genal spine. Facial suture running outward from the eye, and curving inward to join the anterior margin approximately in front of the eye, a *Niobe*-form suture. Neck furrow deep and wide, nuchal segment unornamented.

Pygidium subequal in size to the cephalon, nearly twice as wide as long; axial segment broad, tapering strongly posteriorly and marked by four strong and wide furrows in the anterior part, this furrowed part being just less than half the length of the whole; remainder devoid of furrows; moderately raised in the anterior part, but strongly so posteriorly, where the dorsal furrows are extremely well marked. At extreme posterior end axial lobe produced into a long spine, in length about two-thirds of the length of the rest of the pygidium. Strong and wide lateral furrows corresponding to all of the axial furrows except the posterior one; these lateral furrows directed more and more backward, so that the posterior pair are nearly parallel. Around the margin of the pygidium a broad flat border, at the front one-tenth the width of whole pygidium decreasing posteriorly; at posterior tip of pygidium margins of this border curving inward to form a reën-

[5] White, C. A., Report on invertebrate fossils collected in portions of Nevada, Utah, etc.: *U. S. Geogr. Surveys West 100th Mer., Rept.*, vol. 4, pt. 1, p. 56, pl. 3, figs. 5*a*–5*d*, 1877.

[6] Ruedemann, Rudolf, Cephalopods of the Beekmantown and Chazy formations of the Champlain basin: *New York State Mus., Bull.* 90, p. 444, 1906.

[7] Billings, Elkanah, *Paleozoic fossils of Canada*, vol. 1, p. 253, figs. 239*a*, 239*b*, 1865.

trant under the axial spine; axial lobe prolonged over this reëntrant; lateral furrows continuing laterally with undiminished strength as far as the border, but ending there abruptly; lateral lobes descending to it with great abruptness. Dimensions of specimens of average size: width, 24 mm.; length to base of spine, 11.5 mm.; length of spine, 8 mm.

Thorax known from isolated segments only; axial part strongly bowed backwards, lateral parts with deep furrows and blunt terminations.

Surface of smaller specimens smooth. In cranidia with glabella more than 6 mm. long, and in pygidia, exclusive of spine, more than 8 mm. long, outer surface covered with pustules. A pustulose exterior is therefore characteristic of the adult.

Exceedingly common at locality H, Swan Peak formation south of Mount Pisgah, Utah.

The characteristic feature of this genus may have been foreshadowed by such Upper Cambrian forms as *Megalaspis?* sp. Westergard[7] (pygidium no. 3), in which the axial lobe projects backwards nearly to the posterior end of the pygidium, and appears to be raised high above it even at its posterior end.

Few asaphids have been reported from Ordovician rocks of the Cordillera of the United States. *Xenostegium goniocercum* (Meek)[8] occurs at Flathead Pass, Mont., and at Malade City, northern Utah. It is known only from pygidia, which have a nearly smooth upper surface, and the traces of nine or ten segments on the under surface of the axial

[7] Westergard, A. H., *Sveriges Olenidskiffer 2, Fauna 1, Trilobita*, p. 180, pl. 2, fig. 31, 1922.

[8] Meek, F. B., Preliminary paleontologic report: *U. S. Geol. Surv. Terr., 6th Ann. Rept.*, pp. 465, 480, 1873. Walcott, C. D., Cambrian geology and paleontology, V: *Smithson. Misc. Coll.*, vol. 75, no. 3, p. 127, 1925.

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EXPLANATION OF PLATE 24

P.R.M. no. 2.3501 indicates catalogue number of Peter Redpath Museum, McGill University.

FIGS. 1—*Clonograptus flexilis* (Hall), much compressed specimen (×3/5) from loc. E., collected by Dr. Chamberlain. Mus. Comp. Zool. no. 510. (p. 241)

2—*Didymograptus bifidus* (Hall), (×2), showing typical appearance of this species at loc. H, P.R.M. no. 2.3501. (p. 241)

3, 4—*Lingulella bellisculpta* Clark, n. sp. 3, Slab (×2) from loc. H; arrow points to holotype, P.R.M. no. 2.3502. 4, Portion of holotype much enlarged. (p. 242)

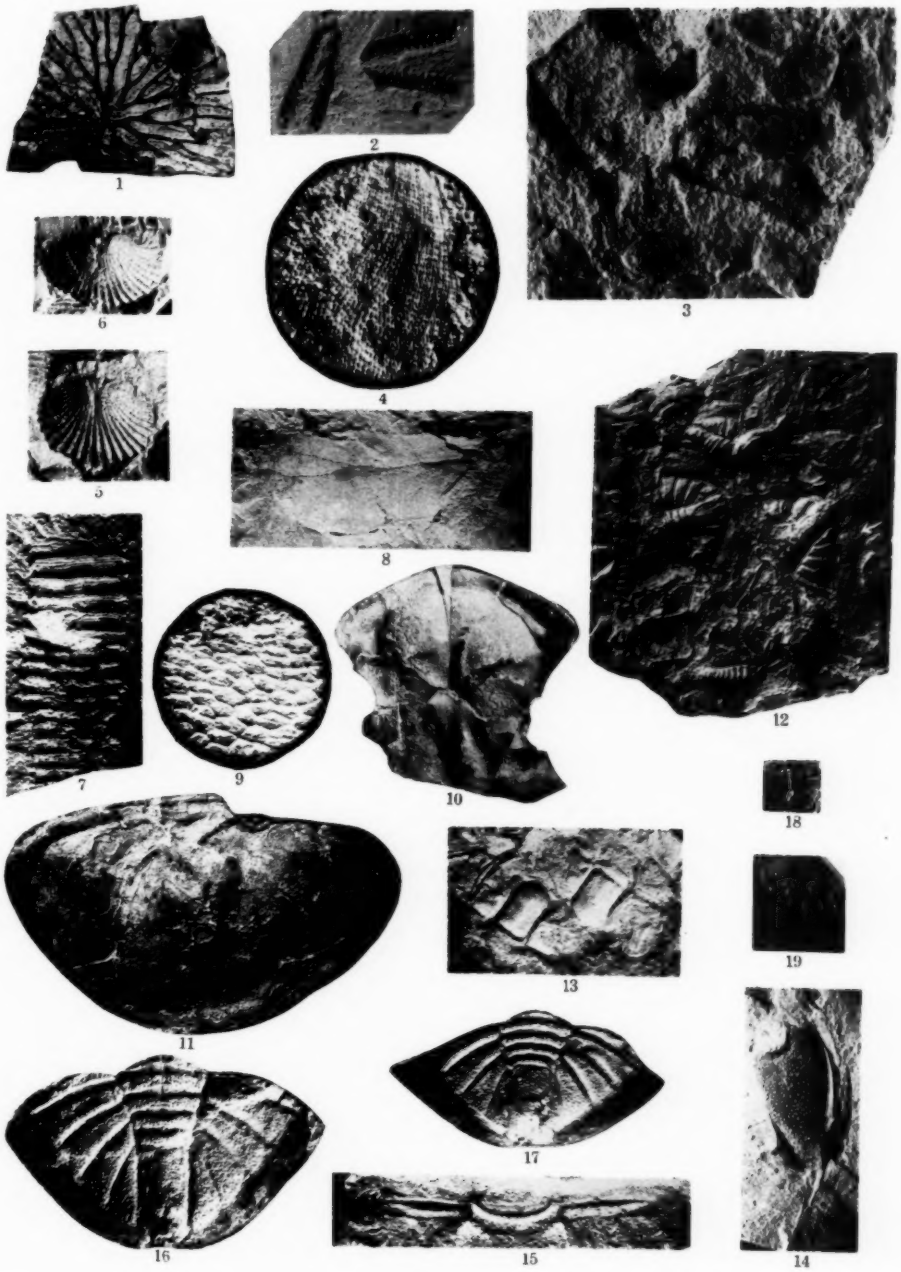
5, 6—*Orthis michaelis* Clark, n. sp. 5, Holotype (×1), a brachial valve, P.R.M. no. 2.3503. 6, Paratype, brachial valve (×1), showing mould of the cardinal process, P.R.M. no. 2.3504. Loc. G. (p. 242)

7—*Protocycloceras debilis* Clark, n. sp., holotype (×1), P.R.M. no. 2.3505. Loc. H. (p. 242)

8, 9—*Tuzoia subtile* Clark, n. sp. 8, Holotype (×3/5), carapace from loc. H, P.R.M. no. 2.3506. 9, Portion of the surface of holotype enlarged. (p. 245)

10, 11—*Bellefontia chamberlaini* Clark, n. sp. 10, Holotype (×1), cranidium, P.R.M. no. 2.3507. 11, Pygidium (×3/5) associated with the cranidium, fig. 10; superimposed on the axial lobe is a smaller but specifically identical pygidium; P.R.M. no. 2.3508. Loc. A. (p. 245)

12–19—*Eleutherocentrus petersoni* Clark, n. gen. and sp. 12, Slab (×1) with four well preserved pygidia and scattered cranidia, free-cheeks, and thoracic segments; arrow points to holotype, P.R.M. no. 2.3509, which, though incomplete, shows the spine's independence of the posterior margin of the pygidium. 13, Slab (×1) with two cranidia, P.R.M. no. 2.3510. 14, Free-cheek (×1) of a large individual, showing pustulose surface of adult, P.R.M. no. 2.3511. 15, Thoracic segment (×6/5), P.R.M. no. 2.3512. 16, One of the largest pygidia (×1), P.R.M. no. 2.3513. 17, Fairly large pygidium (×6/5) showing reëntrant in posterior margin; axial spine is lost; P.R.M. no. 2.3514. 18, One of the smallest specimens (×3/5), with well developed spine, P.R.M. no. 2.3515. 19, Small pygidium (×1) with furrows subdued, P.R.M. no. 2.3516. Loc. H. (p. 243)




Clark, Ordovician Invertebrates

lobe. *X. belemnurum* (White),[9] which comes from Lower Ordovician rocks of Nevada, seems to be closely related species. It differs in several important respects, however. White's species possesses a nearly flat border which does not appear to narrow posteriorly, and which bears a short spine. The segmentation is indistinct, though the illustration shows eight axial furrows and four pairs of lateral ones. Moreover it is only half as wide again as long. The strong posterior elevation of the axial lobe of the pygidium in our specimens is not noted in White's description.

This species is dedicated to Dr. William Peterson, Director of the State Agricultural College, Logan, Utah.

BELLEFONTIA[10] CHAMBERLAINI Clark, n. sp.
Plate 24, figures 10, 11

Cranidium when complete about 30 mm. long; glabella scarcely outlined, widest in front, with anterior border rounded and marked by a deep frontal furrow; this furrow shallowest in the middle, continued beyond the limits of the glabella towards the free-cheeks. Towards the posterior part of glabella a sharp but small median tubercle, borne on a medium ridge, which may, however, be merely a result of the crushing of the specimen. No trace of glabellar furrows, neck-ring not preserved. Frontal limb of fixed cheeks slightly convex. Course of facial suture like that of type species save that where it leaves the proximity of anterior margin of the cephalon to turn inwards to the eye, the deflection is approximately 90°; before reaching the eye the suture runs for 7 mm. in a nearly straight line, then curves outwards to reach the eye, instead of being sharply deflected as in *B. collieana* (Raymond). Exact position of eyes unknown. The specimen was crushed before the consolidation of the sediment in which it was imbedded, one result being a longitudinal split extending from the anterior margin nearly to the center of the glabella. If restored to its original condition it would probably appear with a fair degree of relief.

Loc. A, Garden City formation, Logan Canyon, Utah.

This species differs from *B. collieana* (Raymond) chiefly in the course of the facial sutures; and from *B. nonius* Walcott in having the glabella well marked off in front, and by a proportionately wider anterior rim, which is slightly convex.

Associated with the cranidium described above are two pygidia, one superposed on the other. These resemble in form and proportion the pygidia of *B. nonius*, save that no segmentation at all can be seen. Organic remains are scarce at Locality A, and it is highly probable that these pygidia belong to the associated cranidium. Width of the large specimen 100 mm., of the small one 40 mm.

PHYLLOCARIDA

TUZOIA[11] SUBTILE Clark, n. sp.
Plate 24, figures 8, 9

This species is rather rare in the *Didymograptus bifidus* beds, and unknown elsewhere. All of the specimens are incomplete, the type being the least so. Phyllocarids are not so common in the Ordovician as is commonly supposed. They are known from the Beekmantown (*Caryocaris*), and from the Trenton of Ontario (*Aristozoe*), but I can find no authoritative record of others in the Ordovician of this continent. In Europe *Caryocaris* is reported from the Arenig, and *Ceratiocaris* probably occurs in the Tremadoc.

Carapace of medium size, probably 60 mm. long when complete; width of largest specimen, 24 mm. Dorsal rim straight and on our specimens the greatest longi-

[9] White, C. A., *op. cit.*, p. 59, pl. 3, fig. 9. Walcott, C. D., *op. cit.*, p. 125.

[10] *Bellefontia* Walcott (not Ulrich), Cambrian geology and paleontology, V: *Smithsonian Misc. Coll.*, vol. 75, no. 2, p. 54, 1924; vol. 75. no. 3, p 69, 1925.

[11] Resser, C. E., New Lower and Middle Cambrian Crustacea: *U. S. Nat. Mus., Proc.*, vol. 76, pp. 1–18, pls. 1–7, 1929.

tudinal axis, though incomplete preservation may account for this. Ventral rim shows no signs of setae. No eye-nodes can be recognized; in two or three places there are elevations which resemble nodes, but the pattern of the ridges is continued across them with no interruption, and it is likely that they represent the adjustment during preservation of the carapace to ostracodes, which are present in great numbers and of appropriate size. No trace of a rostrum is to be seen, nor are there any abdominal segments preserved. The ornamentation is remarkable; it consists of a delicate net-work of fine ridges which toward the posterior end is similar to that shown in the genotype, toward the anterior end the pattern becomes more radial, and resembles the venation of insect's wings.

Loc. H, Swan Peak formation south of Mount Pisgah, Utah.

A glance at the genotype, *T. retifera* Walcott,[12] will show that its much greater size and coarser pattern of ridges serve to differentiate it from the present species. In both species the carapace is exceedingly thin, and has suffered somewhat accordingly. Walcott does not mention the presence or absence of eye-lobes, and none can be made out from the illustration; Resser states that none was observed. It is not impossible that this new species will be shown to deserve a new generic name. The apparent absence of spines, if shown to be real, would be sufficient to separate it from *Tuzoia*, but the material at hand does not justify the erection of a new genus.

[12] Walcott, C. D., Cambrian geology and paleontology, II: *Smithsonian Misc. Coll.*, vol. 67, no. 6, p. 187, pl. 33, fig. 2, 1910.

JOURNAL OF PALEONTOLOGY, VOL. 9, NO. 3, PP. 247–250, PL. 25, APRIL, 1935

# NEW MISSISSIPPIAN SPECIES OF *STROPHALOSIA* FROM MISSOURI[1]

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St. Louis, Missouri

ABSTRACT

Three species of the brachiopod genus *Strophalosia* are described from the Warsaw formation (Mississippian) of St. Louis County, Missouri. These resemble the typical Permian forms of the genus more than any other members of the Strophalosiinae. The relations of *Strophalosia* King, *Etheridgina* Oehlert, *Aulosteges* Helmersen, and *Leptalosia* Dunbar and Condra are discussed.

The Warsaw formation in St. Louis County, Missouri, has yielded several new species of the genus *Strophalosia*. Representatives of this rather remarkable genus are rare in North America, and Mississippian examples have thus far been reported only from the Kinderhook and New Providence beds of the Mississippi Valley.

Many dissimilar forms have been referred to *Strophalosia* King, 1844, in the past. Greger[2] in 1920 placed in *Etheridgina* Oehlert certain minute, adherent brachiopods that are attached by cementation of the greater part of the pedicle valve "instead of at the beak as in the true *Strophalosias*." These include the American species *S. radicans* Beecher, *S. keokuk* Beecher, *S. scintilla* Beecher, and *S. spondyliformis* Girty?. Dunbar and Condra[3] in 1932 erected the genus *Leptalosia* to include these thin, adnate, minute productids, selecting *S. scintilla* Beecher as the genotype. No mention was made of the earlier use of the name *Etheridgina* for these American forms. Greger noted the presence of a cardinal area in *Etheridgina*, whereas Dunbar and Condra state that the complete absence of an area and differences in the structure of the cardinal process distinguish *Etheridgina* from *Leptalosia*. Dunbar and Condra, however, apparently agree with Greger that these minute forms, with their more complete surface of adhesion, are distinct from true *Strophalosia*. The Permian genotype of *Strophalosia* is a relatively larger, thicker-shelled brachiopod, attached only at the beak. The cardinal area is rather well developed in each valve and the cardinal process is prominent. The surface of the pedicle valve is covered with spines and the brachial valve is either spinose, lamellose, or smooth. Brachial ridges are distinct on the interior of the brachial valve.

Apparently the specimens here

[1] Manuscript received November 1, 1933.

[2] Greger, D. K., North American species of the brachiopod *Etheridgina: Geol. Mag.*, vol. 57, no. 678, pp. 535–538, 1920.

[3] Dunbar, C. O., and Condra, G. E., Brachiopoda of the Pennsylvanian system in Nebraska: *Nebraska Geol. Survey, Bull.* 5, 2d ser., pp. 260–264, 1932.

described from the Warsaw formation are more closely related to the typical Permian forms of *Strophalosia* than to any other genus of the Strophalosiinae. The presence of a cicatrix of cementation, the absence of spinules on the deltidium, and the relatively low and broad cardinal area serve to distinguish our examples from *Aulosteges* Helmersen. Within the genus *Strophalosia*, they show certain affinities of general appearance to the broad-hinged but less spinous forms, *S. cymbula* Hall and Clarke and *S. beecheri* Rowley.

### Localities

*Locality 1.*—NW. ¼ SE. ¼ sec. 10, T. 44 N., R. 5 E. Abandoned road from Meramec River to Osage Hills station; one-eighth of a mile south of Osage Hills station on the St. Louis and San Francisco Railroad, St. Louis County, Missouri.

*Locality 2.*—SW. ¼ sec. 14, T. 44 N., R. 5 E. On concrete highway (Antire road) 300 yards east of bridge over Meramec River, St. Louis County, Missouri.

## DESCRIPTIONS OF SPECIES

### Strophalosia orbiculata Hinchey and Ray, n. sp.

Plate 25, figures 1–7

Shell small and thin, not attached in the mature stage, subcircular to circular in outline, the hinge-line about half the greatest width. Dimensions of one of the cotypes: Length 7.5 mm., width 7.4 mm., convexity of pedicle valve approximately 1.5 mm., length of hinge-line 3.7 mm.

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### Explanation of Plate 25

Figs. 1–21 magnified 2 diameters; figs. 22-31, natural size.

Figs. 1–7—*Strophalosia orbiculata* Hinchey and Ray, n. sp., Washington Univ. no. 730,001. 1, Brachial view of a nearly complete specimen. 2, 3, Pedicle views of other specimens. 4, 5, Pedicle and brachial views of a distorted specimen. 6, 7, Pedicle views of another specimen. Loc. 1. (p. 248)

8–11—*Strophalosia subelliptica* Hinchey and Ray, n. sp., Washington Univ. no. 730,002. 8, Nearly complete pedicle valve. 9, 10, Pedicle and brachial views of a nearly complete specimen. 11, Interior of brachial valve of a larger example. Loc. 2 (p. 249)

12—*Strophalosia* sp., Washington Univ. no. 730,003, pedicle valve showing large surface of attachment with strong regularly spaced spines along its margin. Loc. 2 (p. 250)

13–21—*Strophalosia fortispinosa* Hinchey and Ray, n. sp., Washington Univ. no. 730,004. 13, 14, Interior of a brachial valve showing the brachial furrows and exterior of same. 15, Brachial valve showing pustulose inner surface. 16, 17, Pedicle and brachial views of a nearly complete specimen. 18, Exterior of a brachial valve showing lateral distortion during growth. 19, Pedicle valve showing scar of attachment. 20, Pedicle valve, broken at the cicatrix and showing the muscle scars on the interior of the brachial valve. 21, Distorted brachial valve. Loc. 1. Note that fig. 16 is inverted. (p. 249)

22, 23—*Haliotis elsmerensis* Vokes, n. sp., holotype, Univ. California Mus. Inv. Paleont. no. 32465. 22, Top view, showing spire and sculpture; 23, right side, showing convexity of shell and angulation below the holes. (p. 251)

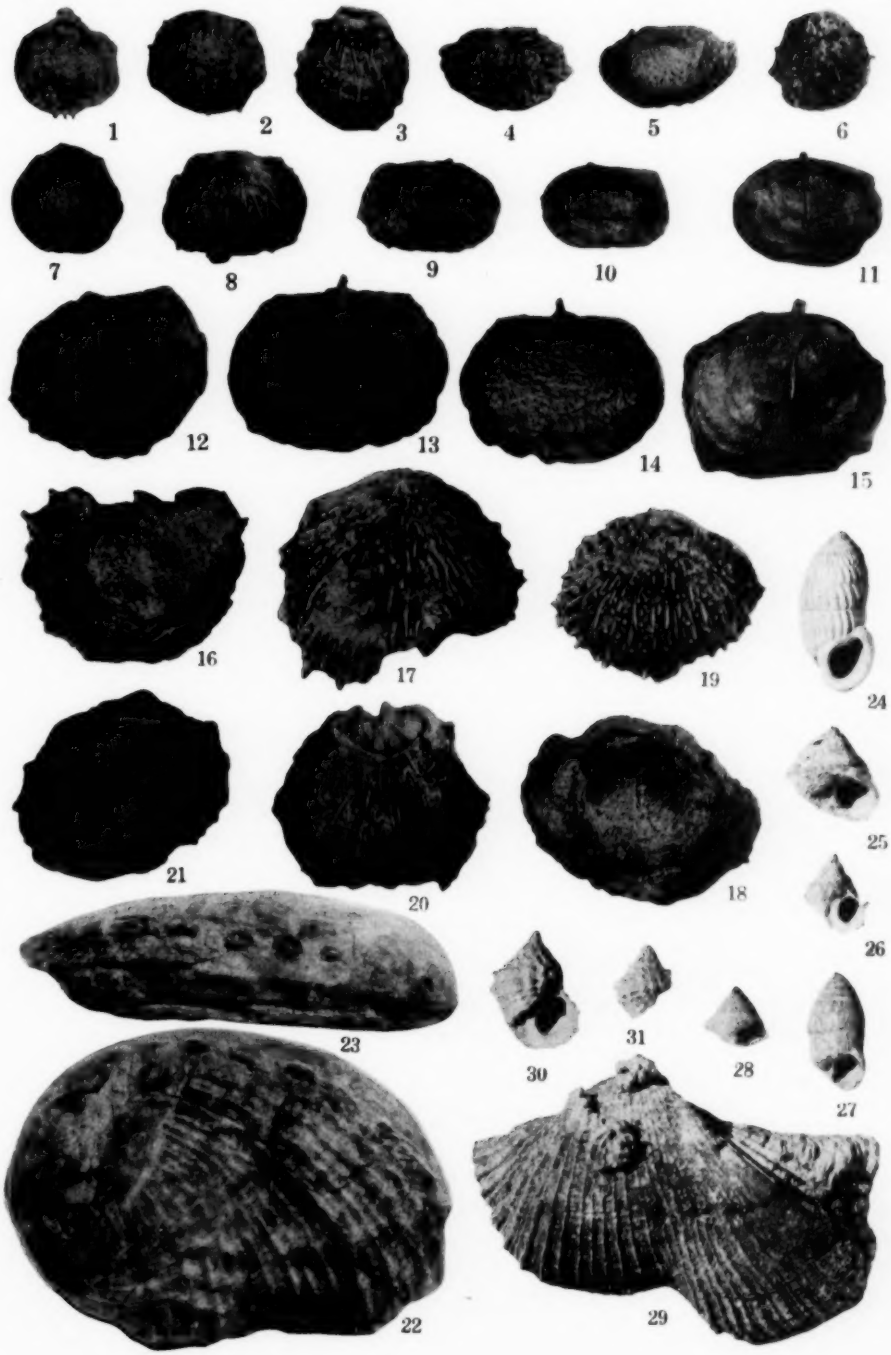
24—*Arca occidentalis* Philippi var. *marielina* Richards, n. var., holotype. Loc. 12. (p. 256)

25—*Cerion dickersoni* Richards, n. sp., holotype. Loc. 9. (p. 257)

26—*Cerion* n. sp. Loc. 5. (p. 257)

27–28—*Modulus modulus* (Linne) var. *altispirus* Richards, n. var. 27, holotype. 28, paratype. Loc. 12. (p. 257)

29–31—*Echinella nodulosa* Gmelin var. *matanzensis* Richards, n. var. 30, holotype. 29, 31, Paratypes. Loc. 6. (p. 257)




Hinchey and Ray, Mississippian Brachiopods
Vokes, Pliocene Mollusk
Richards, Pleistocene Mollusks

Pedicle valve only slightly convex, the greatest convexity near the middle; cicatrix rather inconspicuous in most of the cotypes, but quite large and prominent in one specimen (fig. 3); cardinal area a broad low triangle, the cardinal margins sharply angular and the posterior margins gently convex from the beak to the cardinal extremities; delthyrium small and apparently closed by the deltidium; cardinal area an almost flat surface lying in the plane of the valve. The surface of the valve is well covered with strong spines of relatively large size; spine bases occur at irregular intervals of about 0.3 mm.; the spines tend to radiate anteriorly and laterally from the umbo; lines of growth are irregular and rather inconspicuous. Interior not observed.

Brachial valve gently concave, its curvature following that of the opposite valve; cardinal area much smaller than that of the pedicle valve and rather inconspicuous in most of the specimens; surface marked by irregular but rudely concentric lines of growth; spines absent from this valve, and the surface smooth, save for the sublamellose appearance of the growth lines. Interior not definitely observed.

This species resembles somewhat *S. subelliptica* described below, but is distinguished from that species by its circular outline and its relatively shorter hinge-line.

*Occurrence.*—Warsaw formation of the Meramec group. Rather common at Loc. 1, less common at Loc. 2. Figured cotypes, Loc. 1.

STROPHALOSIA SUBELLIPTICA Hinchey and Ray, n. sp.

Plate 25, figures 8–11

Shell small and delicate, probably unattached in the mature condition, subelliptical in outline, the hinge-line being about two-thirds the greatest width. The dimensions of one of the cotypes are: Length 6 mm., width 9.3 mm., convexity of the pedicle valve about 1 mm., length of hinge-line 6 mm.

Pedicle valve very slightly convex, the point of greatest convexity lying immediately behind the center of the shell; cicatrix minute and inconspicuous; cardinal area a broad triangle, averaging slightly less than 1 mm. in height, the cardinal margins slightly convex from the beak to the cardinal extremities; the delthyrium small, closed by the deltidium. Although the specimens are somewhat crushed, the cardinal area is not in the plane of the valve, but is almost normal to it. Numerous spines, 0.1 mm. to 0.3 mm. in diameter, are scattered over the surface of the pedicle valve at intervals of about 0.8 to 1.5 mm. in an irregular pattern which follows the faintly visible growth lines. These tubular spines grow away from the umbo to the lateral margins and the front of the shell. Some of the broken spines measure 3 mm. in length. Interior not observed.

Brachial valve convex, following the configuration of the pedicle valve; cardinal area smaller and lower than that of the opposite valve; shell surface lamellose; cardinal process erect, anteriorly bifid, posteriorly trifid, supported laterally by the socket plates and confluent with a well-defined median septum which extends over half the length of the valve.

This species somewhat resembles *S. orbiculata*, described above, but differs from that species in its subelliptical outline, its longer hinge-line, and the attitude of the plane of the cardinal area.

*Occurrence.*—Warsaw formation of the Meramec group. Rather common at Loc. 2; rare at Loc. 1. Figured cotypes, Loc. 2.

STROPHALOSIA FORTISPINOSA Hinchey and Ray, n. sp.

Plate 25, figures 13–21

Shell of medium size, concavo-convex, and rather thin; apparently attached throughout life, but may be free in mature stages; generally wider than long, hinge-line about two-thirds the width of the shell; outline somewhat broadly triangular. Dimensions of an average specimen: Length 15 mm., width 18 mm., con-

vexity of the pedicle valve approximately 4 mm., length of hinge-line 11 mm.

Pedicle valve convex, the greatest convexity near the middle with a slight geniculation in the later growth stages; cicatrix prominent in most specimens and restricted to the umbonal portion of the valve; cardinal area a nearly flat, broad, low, triangle, with acute base angles; the posterior cardinal margins somewhat obscured by irregular shell growth at the surface of attachment; delthyrium narrow and apparently closed by the deltidium. Diameter of the cicatrix nearly one-half the greatest width of the shell. Exterior of the valve almost completely covered with large, strong, tubular spines, which are irregular crowded over the entire shell; the hollow center equal to one-half the diameter of the spines, which radiate anteriorly and laterally from the umbo; irregular lines of growth inconspicuous and somewhat masked by the abundance of spines. Interior not observed.

Brachial valve concave, its curvature following that of the opposite valve; cardinal area much smaller than that of the pedicle valve; hinge-line straight, the extremities marking the termination of the curvature of the outline; outline curving smoothly from the greatest width toward the hinge-line. Cardinal process strong, trifid posteriorly and bifid anteriorly; median septum well-developed and about half the length of the valve. Interior marked by rather prominent brachial furrows which follow the outline of the shell; adductor scars appear to be subtriangular prominences near the median septum (fig. 20). Rather prominent pustules are developed on the anterior half of the interior and seem to be produced in the direction of the spines of the opposite valve (fig. 15). Exterior of the brachial valve marked by concentric growth lines but free from spines.

The distinctive shape of examples of this species readily separate them from *S. orbiculata* and *S. subelliptica*.

*Occurrence.*—Warsaw formation of the Meramec group. Rather common at Loc. 1, not found at Loc. 2.

STROPHALOSIA sp.
Plate 25, figure 12

A single specimen, which undoubtedly belongs to this genus, has a large cicatrix covering the greater portion of the surface of the pedicle valve. At the anterior border of this scar of attachment long, strong spines, about 0.5 mm. in diameter, are spaced at rather regular intervals, and about 1 mm. apart at their bases. The general appearance of this shell is quite unlike any of the other species herein described, but continued search has failed to produce more than this single specimen.

*Occurrence.*—Warsaw formation of the Meramec group. Loc. 2.

JOURNAL OF PALEONTOLOGY, VOL. 9, NO. 3, PP. 251–252, PL. 25, APRIL, 1935

# A NEW SPECIES OF *HALIOTIS* FROM THE PLIOCENE OF SOUTHERN CALIFORNIA[1]

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ABSTRACT

*Haliotis*, rare in the fossil state, is represented by a new species from the Lower Pliocene of southern California. The Cretaceous form *Haliotis lomaensis* F. M. Anderson, is considered to be a true *Haliotis*.

Dr. W. P. Woodring has recently described two new species of *Haliotis* from the Miocene of California.[2] In these papers he has discussed the rarity of the fossil remains of *Haliotis*. In 1929 the writer collected a specimen representing the genus from the Pliocene of Elsmere Canyon Los Angeles County, California. This proved to belong to a new species, and is here described.

Genus HALIOTIS Linné

LINNÉ, *1758*, Syst. Nat., ed. 10, p. 779. Type, by subsequent designation (MONTFORT, *1810*, Conch. Syst., vol. 2, p. 119) *Haliotis asininus* Linné, Recent, Indo-Pacific.

Iredale[3] and Woodring have both commented upon Montfort's designation of *H. asininus* as the type of the genus. In Woodring's discussion in the Journal of Paleontology he mentioned the Cretaceous species *H. lomaensis* F. M. Anderson,[4] saying:

The specimen is very small (length 12.7 mm., width 9.2 mm.) and smooth, aside from a shallow groove that lies above the four narrow perforations and a faint ridge lying above the groove. The shell is broken away at the apex, but aside from a slight twist of about 90 degrees no trace of a spire can be seen. The shell also is broken away along the edge adjoining the perforations, revealing a narrow shelf, as in *Haliotis*. In view of the antiquity of this specimen, and in view of the absence of a well-defined spire, it is doubtful whether it is a genuine *Haliotis*, though it may represent an ancestral genus.[5]

Recently the writer examined Anderson's specimen at the California Academy of Sciences (Invert. Pal. Coll. no. 65). The shell is broken away with the spire, and only the 90° twist is left, but the broken surface of the matrix filling the shell gives evidence that the spire was of greater extent. The four perforations are narrow and elongated, and the shelf at the edge adjoining the perforations is well developed. In the writer's opinion the specimen is certainly a *Haliotis*, and represents a young individual.

HALIOTIS ELSMERENSIS Vokes, n. sp.

Plate 25, figures 22, 23

Holotype (Univ. Calif. Mus. Invert. Pal. 32465) an almost complete individual 62 mm. long, 55 mm. wide, and 18 mm. in greatest height; complete, it was

[1] Manuscript received July 1, 1933.

[2] Woodring, W. P., A Miocene *Haliotis* from southern California: *Jour. Paleontology*, vol. 5, pp. 34–39, pl. 6, March, 1931. A Miocene mollusk of the genus *Haliotis* from the Temblor Range, California: *U. S. Nat. Mus., Proc.*, vol. 81, art. 15, 1932.

[3] Iredale, Tom, On some misapplied molluscan generic names: *Malac. Soc. London, Proc.*, vol. 9, p. 260, 1911.

[4] Anderson, F. M., Cretaceous deposits of the Pacific Coast: *Calif. Acad. Sci., Proc.*, 3d ser. Geology, vol. 2, no. 1, p. 75, pl. 9, fig. 183, 1902.

[5] Woodring, W. P., *Jour. Paleontology*, vol. 5, p. 35, 1931.

probably 25 mm. longer. Spire 12 mm. above ventral edge of the shell.

Long-ovate, flat *Haliotis* with indeterminate number of open holes; seven open, five closed holes on the holotype; shell built up to form slight collar about each; slightly angulated along the row of holes. Spire but slightly submarginate, low. Sculpture of approximately 16 low, rounded spiral cords of unequal strength, separated by interspaces approximately three times as wide as the cords; in most, but not all of these interspaces a small rounded interrib, also of varying strength; several crude waves radiate out toward the periphery of the shell from the spire; growth lines tend to be pronounced.

*Discussion.*—*H. elsmerensis* appears to be related more closely to *H. rufescens* Swainson than to any of the other West Coast haliotids. Both forms have waves radiating from the spire to the periphery of the shell, but *H. elsmerensis* differs from *H. rufescens* in having fewer and more rounded ribs, separated by interspaces approximately three times as wide as the ribs. *H. assimilis* Dall and *H. kamtschatkana* Jonas have a more elevated shell and more ribs than *H. elsmerensis;* and *H. corrugata* Gray and *H. kamtschatkana* have a surface roughened with corrugated humps, lacking in *H. elsmerensis*. *H. fulgens* Phillippi is sculptured by numerous closely set rounded ribs.

Grant and Gale[6] report the occurrence of three of the recent species of *Haliotis* in the Pliocene of southern California: *H. corrugata, H. fulgens,* and *H. rufescens.* The record of *H. fulgens* is from Elsmere Canyon, the type locality of *H. elsmerensis.*

*Type locality.*—Elsmere Canyon, Los Angeles County, at the extreme northwest flank of the San Gabriel Range, just east of San Fernando Pass, in the NW. ¼ NW. ¼ SE. ¼ sec. 17, T. 3 N., R. 15 W., Mt. San Bernardino Base and Meridian; in the bed of the canyon about 15 feet downstream from the contact with the granite. The matrix is a coarse, almost pure quartz sandstone.

*H. elsmerensis* occurs in strata of Lower Pliocene age which has been correlated with the Jacalitos formation of the San Joaquin Valley. English[7] lists 57 species from this region including *Chione elsmerensis* English, *Astrodapsis fernandoensis* Pack, *Arca trilineata* Conrad, *Pecten ashleyi* Arnold and *Pecten healeyi* Arnold, which together with fragments of *Procamelus* bones establish the Lower Pliocene age of the formation.

[6] Grant, U. S., IV, and Gale, H. R., Catalogue of the Marine Pliocene and Pleistocene Mollusca of California: *San Diego Soc. Nat. Hist., Mem.*, vol. 1, pp. 845–846, 1931.

[7] English, W. A., The Fernando group near Newhall, California: *Univ. Calif. Publ., Bull. Dept. Geol.*, vol. 8, no. 8, 1914.

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# PLEISTOCENE MOLLUSKS FROM WESTERN CUBA[1]

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ABSTRACT

Pleistocene mollusks from twelve localities in Matanzas and Pinar del Rio provinces, Cuba are listed and interpreted as indicating little change in climate. Four new forms are described.

In January, 1933, I had the opportunity of making a brief visit to a number of Pleistocene localities in the provinces of Matanzas and Pinar del Rio, Cuba.[2] This work was done at the suggestion of Dr. Roy E. Dickerson, Chief Geologist of the Atlantic Refining Company of Cuba. To Doctor Dickerson and the staff of the company I am deeply indebted for much valuable assistance in the field. In addition, I was very fortunate in having as a companion on several of my trips, Dr. Pedro J. Bermudez, who was kind enough to point out to me many interesting localities. Thanks are also due the Carnegie Museum of Pittsburgh, Pennsylvania, for financial aid. A complete set of the Pleistocene fossils has been deposited in that museum.

## PREVIOUS WORK

Very little seems to have been written on the Pleistocene of Cuba. Hill (1895, p. 267), in a report written for Alexander Agassiz, remarks:

> The most striking feature in the topography of Cuba consists of the well-defined terraces and benches which mark its coast in many places. They are often so distinct, especially at the east end of the island, that their continuity is traceable for many miles as they rise abruptly from the water's level, one above the other in a series of cliffs. On the west end of the island they are not so distinctly visible from any single point of view, for the flat benches are much wider, but they are nevertheless traceable. In other places denudation has destroyed them.
>
> Besides these benches and terraces, whose integrity is distinctly preserved, remnants of older and more denuded levels can be traced.

Hill states that these elevated benches and terraces with the exception of the "soborruco" or modern coral reef, are all beach and erosion plains exposed by the rapid elevation of the island in post-Tertiary time.

Crosby (1882, p. 128) regarded all the terraces "from twenty up to nearly two thousand feet above the sea" as fringing coral reefs that have been lifted above the sea. He explains them by saying:

> Cuba during post-Tertiary time has experienced a powerful elevation; but there are good reasons for believing that the upward progress of the land was not uninterrupted. The reefs, in fact, are witnesses for both sides, testifying with nearly equal distinctness to both elevation and subsidence.

Hayes, Vaughan and Spencer

[1] Manuscript received July 12, 1934.

[2] For narative of trip and description of recent mollusks collected, see Richards, 1933, 1934, in bibliography on page 258.

(1902) have given probably the most complete notes on the geology of Cuba. Concerning the Pleistocene they say:

> Surrounding the greater portion of Cuba, but especially along the northern coast and bordering the southern Coast of Santiago from Cape Maisi to Cape Cruz, is a low coastal shelf never exceeding a maximum elevation of 30 or 40 feet. There is beneath this shelf sometimes a lower terrace some five or six feet above the water's edge. Both of these terraces are composed of elevated coral reef rock. The material is a limestone presenting an extremely rough upper surface, and replete with the remains of numerous species of corals which are all, so far as examined, at present living in the surrounding Antillean seas. These reefs have been formed and elevated within very late geologic time.

Some of the terraces at higher altitudes, referred questionably to earlier periods, may well be Pleistocene.

In discussing the Canal Zone and related areas, Vaughan (1919) comments further on the geology of Cuba, particularly in regard to the tertiary and quaternary coral reefs.

Rise and fall of sea-level concomitant with retreat and advance of continental ice sheets is commonly regarded as one of the main causes of the Pleistocene terraces of the eastern coast of the United States (Antevs, 1929; Cooke, 1930; etc). These terraces appear to be horizontal, or practically so, and there is very little evidence of pronounced differential crustal movements. That glacial control of sea-level played a part in the Pleistocene history of Cuba has been suggested by various writers, but the data indicate a more complicated history involving crustal movements and tilting. Vaughan (1919) recognizes both

> emergence of large areas probably due to withdrawal of water to form the continental ice sheets; also occillation of land areas by differential crustal movement; and in recent time submergence of land areas probably resulting from deglaciation, except local differential crustal movements in places producing uplift.

Taber (1931), working in the Sierra Maestra region in eastern Cuba, believes that

> during the Pleistocene there was an emergence probably in part due to withdrawal of water to form continental ice caps, but also due to uplift and northward tilting along the coast. Submergence, resulting from deglaciation, probably accounts for the modern coral limestone on both the La Cruz marl and the older igneous rocks along the coast. These limestones now form coastal terraces because the uplift and northward tilting has continued intermittently during Recent time.

Later, Taber (1932) remarks:

> The hills [between Santiago and the mouth of the Rio Bacanao] were formed by uplift along faults in Late Pleistocene time and were then submerged by rise of sea-level at the close of the Pleistocene. Uplift of the land in Recent time has again exposed the hills.

Meinzer (1933) working in the Guantanamo Bay region, also recognizes both emergence and subsidence in Pleistocene time.

The fossils listed in this paper were found in western Cuba on the north coast of the provinces of Matanzas and Pinar del Rio. It is likely that Pleistocene and Recent history of the western part of the island was as complicated as that of the eastern part and that various crustal movements took place in this period.

Glacial control alone could hardly account for the highest marine levels, such as marine shells at Yumuri, near Matanzas, and Hato Nuevo, 25 miles southeast of Cardenas, 350 feet above sea-level; and coral of probable Pleistocene age about 200 feet above sea-level near Colon.

Because of the short time spent in the field, no attempt is made here to discuss the stratigraphy and physiography of western Cuba, or to correlate the various localities. It is proposed here merely to give brief notes on the localities visited, list the fauna and note its significance.

## FOSSIL LOCALITIES

*Matanzas Bay.*—In describing the Matanzas Bay region Hill (1895) says:

> Two diminutive rivers flow into the harbor, the Yumuri of Matanzas and the San Juan, both emerging suddenly from the highland. The highland or skyland is about 100 meters (350 feet) in altitude, and constitutes a flat topped mesa or plateau north of the Yumuri, and a poorly defined bench against a still higher hilly region south and east of that river. Out of this plainly marked level are carved the sloping and narrow lowlands immediately surrounding the harbor, upon which the city is built. Between the level of the city and the highlands the narrow remnants of a few terraces or pausation plains are faintly traceable. One of these is about 150 feet above the sea, and the other, upon which is located the railway station back of the city, and which constitutes the bench back of the Verseilles church north of the Yumuri River, is about 50 feet.

The lowest terrace adjoining Matanzas Bay (up to 25 feet elevation) is the most fossiliferous, and localities 1 to 8 are on this terrace. On the west side of the Bay, the two lower terraces are very distinct. A few hundred yards from the Bay there is the next higher terrace. At the base of this upper terrace well marked sea caves are cut in the limestone. The terraces of still higher elevation are not as distinct but can readily be traced. Locality 9 is on one of the upper terraces.

Fossils were obtained from the following localities:

1. Limestone on lowest terrace on east side of Matanzas Bay; coral and mollusks in the limestone.
2. Bueyvaquita Playa, east side of Matanzas Bay, 4 km. north of loc. 1.
3. Punta Sabanilla, on west side of Matanzas Bay; coral heads and a few species of mollusks on lowest terrace; some shells in limestone, some loose.
4. 2.5 km. northeast of Punta Sabanilla; similar to loc. 3.
5. 4.0 km. northeast of Punta Sabanilla; similar to locs. 3 and 4.
6. 6.5 km. northeast of Punta Sabanilla; similar to locs. 3, 4, and 5.
7. Railway cut in the city of Matanzas, along Matanzas Bay, near the monument to the Expedicionarios Americanos.
8. Bellamar Playa; limestone near shoreline; few corals and mollusks.
9. Sand in sea cave near road to Ermita de Monserrat; elevation 350 feet.

*Eastern Part of Matanzas Province.*—10. 2.5 km. east of the town of Sabanilla de las Palmas and about 8 km. east of the railway station at Hato Nuevo. About 100 m. west of the Hamel Asphalt Mine there is a conspicuous tar seepage containing seeds, shells, and bones mixed with the tar. The elevation is about 350 feet above sea-level and the fauna definitely suggests a Pleistocene age. Some of the bones were identified by

Prof. Carlos de la Torre as vertebrae of alligators; the molluscan fauna is that of a mangrove or brackish water association. The following notes on the locality were furnished by Doctor Dickerson.

The mangrove fauna indicates, as told by the vertebrae of the alligator's tail, that this seep was active during the Pleistocene. In a manner of speaking for 50,000 to 100,000 years tars arose from the bottom of the Pleistocene sea in somewhat the same manner as the asphaltic tar now arises from Cardenas Bay. Here we are almost surely dealing with seeps on a contact between Tertiary and serpentine.

For a further description of the locality see Hayes, Vaughan and Spencer (1925, pp. 104–5; 1902, pp. 93–94). Berry (1934) has discussed the flora from this locality.

11. 6.5 km. east of Colon, 400 m. north of the Carretera Central (Central Highway). Here Pleistocene(?) coral heads are lying on material containing Oligocene Foraminifera; the elevation is about 200 feet above sea-level.

*Mariel Bay, Province of Pinar del Rio.*—12. Lowest terrace (up to elevation of 25 feet) on the west side of Mariel Bay near the town of Mariel; rich molluscan and coral fauna in limestone and sand bluff.[3]

## PLEISTOCENE FOSSILS COLLECTED IN WESTERN CUBA

The numbers refer to the localities as listed on preceding pages.

### PELECYPODA

*Ostrea parasitica* Gmelin, 9, 12.
*Ostrea frons* (Linné), 12.
*Spondylus americanus* Lamarck, 5, 7.
*Pecten gibbus nucleus* Born, 7.
*Lima scabra* (Born), 5, 12.
*Lima lima caribaea* d'Orbigny, 5, 6.
*Perna alata* (Gmelin), 9, 12.
*Mytilus exustus* Linné, 9.
*Dreissensia* (*Mytilopsis*) *leucopheata* (Conrad), 9, 12.
*Arca umbonata* Lamarck, 5, 6, 12.
*Arca candida* Gmelin, 5, 12.
*Arca reticulata* Gmelin, 5, 6.
*Arca auriculata* Lamarck, 7 (young), 9, 12.
*Arca chemnitzi* Philippi, 9, 12.
*Arca campechiensis* Gmelin, 9 (abundant).
*Arca occidentalis* Philippi var. *marielina* Richards, n. var. (Plate 25, figure 24). Ribs higher and more narrow than in typical *A. occidentalis;* posterior border emarginate, owing to a broad sulcation; the type specimen is slightly injured on the posterior end from the sulcus to the edge of the shell; the sulcation crosses and continues above the line of injury. Length 56 mm.; greatest diameter 32 mm. One specimen, holotype, from the bluffs on the west side of Mariel Bay, Pinar del Rio Province, Cuba (loc. 12). Carnegie Museum, Pittsburgh, Pennsylvania.
*Arca adamsi* Shuttleworth, 12.
*Lucina squamosa* Lamarck?, 12.
*Lucina pennsylvanica* (Linné), 1.
*Lucina jamaicensis* Lamarck, 9.
*Lucina chrysostoma* (Meuschen), 1, 7.
*Codakia orbicularis* (Linné), 1, 5.
*Diplodonta semiaspera* Philippi, 12.
*Chama florida* Lamarck, 6, 12?.
*Chama macerophylla* Chemnitz, 5, 12.
*Cardium muricatum* Linné, 7, 12.
*Cardium medium* Linné, 1, 6, 7, 12.
*Cardium serratum* Linné, 1.
*Cardium spinosum* (Meuschen), 12.
*Venus listeri* Gray, 7, 12.
*Chione cancellata* (Linné), 7, 9, 12.
*Chione granulata* (Gmelin), 9, 12.
*Chione paphia* (Linné), 1, 7, 12.

[3] Considerable Pleistocene has been reported in the western part of Pinar del Rio, in the flat country at the foot of the Sierra de los Organos and in the Peninsula de Guanahacabibes. Sr. Juan F. Larmas, of Guane, recently sent me a specimen of *Tegula fasciata* (Born) from the Pleistocene of Los Acostas.

*Petricola typica* (Jonas), 7.
*Heterodonax* cf. *bimaculata* (Linné), 12.
*Tagelus gibbus* (Spengler), 9.
*Tellina interrupta* Wood, 1.
*Tellina fausta* Donovan, 1, 12.
*Tellina radiata* Linné, 1.
*Semele reticulata* (Linné), 12.
*Semele orbiculata* (Say), 12.

GASTROPODA

*Bulla amygdala* Dillwyn, 10, 1?.
*Siphonaria brunnea* Hanley?, 6.
*Conus mus* Hwass, 5, 6.
*Conus verrucosus* Hwass, 1.
*Drillia* cf. *fuscescens* Gray, 6.
*Olivella nivea* (Gmelin), 1.
*Marginella* cf. *apicina* Menke, 10.
*Turbinella scolymus* Gmelin, 4.
*Mitra granulosa* Lamarck, 6.
*Fasciolaria tulipa* (Linné), 10.
*Nassa vibex* Say, 12.
*Nassa ambigua* (Montfort), 10.
*Caducifer intricatus* Dall, 5.
*Columbella mercatoria* (Linné), 1, 5, 6.
*Murex pomum* Gmelin, 12.
*Cassis testiculus* (Linné), 12.
*Dolium perdix* (Linné), 1.
*Ultimus gibbosus* (Linné), 12.
*Trivia suffusa* Gray, 5.
*Strombus pugilis* Linné, 9.
*Strombus gigas* Linné, 1, 7, 9, 12.
*Cerithium minimum* (Gmelin), 12.
*Cerithium literatum* Born, 1?, 12.
*Cerithium atratum* Born, 12.
*Cerithium* cf. *algicola* Adams, 10.
*Cerithium* cf. *floridanum* Mörch, 6, 12.
*Cerithidea* cf. *costata* (DaCosta), 10.
*Potamides scalatus* (Heilprin), 10.
*Vermetus decussatus* (Gmelin), 5.
*Littorina ziczac* (Gmelin), 6.
*Littorina nebulosa* (Lamarck), 6.
*Melarphe mespilium* (Muhlfeldt), 6.
*Echinella nodulosa* Gmelin var. *matanzensis* Richards, n. var. (Plate 25, figures 29–31). Similar to *E. nodulosa* but with carinae above and below the periphery more pronounced; others reduced; lip slightly smaller than in *nodulosa;* size of shell, as a rule, smaller that the typical *nodulosa*. Holotype, length, 13 mm.; greatest diameter, 11 mm.; paratype, length, 10 mm.; greatest diameter, 8 mm. Type locality: 6.5 km. northeast of Punta Sabanilla on Matanzas Bay, Matanzas Province, Cuba (loc. 6). Also 4.0 km. northeast of Punta Sabanilla (loc. 5). Carnegie Museum, Pittsburgh, Pennsylvania.
*Solarium granulatum* Lamarck, 7.
*Hipponyx antiquata* (Linné), 6.
*Crepidula fornicata* Linné, 9.
*Natica canrena* Lamarck, 1, 7?.
*Polinices lactea* (Guilding), 1.
*Livona pica* (Linné), 6, 12.
*Arene cruentata* (Muhlfeldt), 6.
*Tegula fasciata* (Born), Los Acostas, Pinar del Rio; coll. Sr. Juan F. Larmas.
*Nerita versicolor* Gmelin, 6, 12.
*Neritina virginea* (Linné), 9.
*Modulus modulus* (Linné), 1, 12.
*Modulus modulus* (Linné) var. *altispirus* Richards, n. var. (Plate 25, figures 27–28). Resembles *M. modulus angulatus* Adams, but with spire higher and more pronounced; seven specimens found at Mariel, Pinar del Rio (loc. 12). Holotype, length, 13 mm.; greatest diameter, 13 mm. Carnegie Museum, Pittsburgh, Pennsylvania.
*Fissurella alternata* Say, 5, 6, 12.
*Fissurella barbadensis* (Gmelin), 6.
*Fissurella nodosa* (Born), 6.
*Subemarginula octoradiata* (Gmelin), 6.

(Land species)

*Liguus fasciatus* Müller, 12.
*Cerion* n. sp.[4] (Plate 25, figure 26). Figured specimen, length, 17 mm.; greatest diameter, 9 mm.; whorls, 8. Locality 5. Carnegie Museum, Pittsburgh, Pennsylvania.
*Cerion dickersoni* Richards, n. sp. (Plate 25, figure 25). Subcylindrical; first two whorls smooth; third whorl very finely striate; remaining whorls with rather prominent "wrinkles"; lip prominent; probably closely related to *C. mumiola* (Pfeiffer). Holotype, length, 23 mm.; greatest diameter, 12 mm.; whorls, 8½.

[4] Described in a manuscript by Bermudez; a more complete account of this and the following species is to be included in a forthcoming paper.

Locality 9. Carnegie Museum, Pittsburgh, Pennsylvania.

SCAPHOPODA

*Dentalium* sp., 6.

COELENTERATA

Corals were collected at practically all the localities visited.

CRUSTACEA

*Gecarcinus ruricola* (Linné), 9.[5]
*Balanus* sp., 6.

## SIGNIFICANCE OF THE FAUNA

Of the 94 species of mollusks identified, 88, or all but six, are known from the recent fauna of Cuba or the West Indian region. The four new species or varieties are very closely related to species now inhabiting Cuba. One species, *Potamides scalatus* (Heilprin) from the asphalt mine at Hato Nuevo, is not known from the Pleistocene or Recent, but has been reported from the Pliocene (Caloosahatchie) of Florida.

The fauna does not indicate a climatic difference between the Pleistocene and Recent. This brief reconnaissance suggests that the Pleistocene history of western Cuba was somewhat similar to that of the eastern part of the island, probably involving both oscillation (or at least elevation) of the land by crustal movements and oscillation of the sea level due to glacial variations.

[5] Identification by Dr. Mary J. Rathbun.

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# TERTIARY INSECTS OF THE FAMILY CHRYSOPIDAE[1]

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ABSTRACT

Two American Tertiary genera have been recognized in the family Chrysopidae. A third is proposed in this paper and keys to genera and species are given. One new species is proposed. Fossil forms are not known in Europe. The evolution of the family is discussed.

Although the neuropterous family Chrysopidae is at present cosmopolitan in its distribution, fossil representatives have been found only in North American deposits, and until very recently only in the Miocene shales at Florissant, Colorado. In the summer of 1932 a very fine chrysopid, collected by Allan Caplan in the Miocene shales at Creede, Colorado, was kindly donated by Dr. A. B. Klots to the Museum of Comparative Zoology. A study of this specimen naturally led me to consider the other fossil Chrysopidae, which I soon found deserved further examination and description. This was made possible by the kind assistance of Professor H. F. Wickham, who sent me the types of Florissant Chrysopidae in his possession, and Professor T. D. A. Cockerell, who loaned me an excellent specimen of *Palaeochrysa vetuscula* Scudder; and by the invaluable help of Professor Nathan Banks, who aided me in the taxonomy of certain recent Chrysopidae.

The persistent absence of chrysopids from the European Tertiary, even from such highly fossiliferous formations as the Baltic amber and the Oeningen shales, is very curious, especially in view of the occurrence of closely related fossils in the Jurassic of Bavaria and Turkestan. A few insects collected in the Tertiary rocks of Europe were assigned to the genus *Chrysopa* by older writers, but these have subsequently been proved to belong to other families of Neuroptera. Berendt (3) briefly mentioned the presence of a supposed *Chrysopa* in the Baltic amber, but no specimens have subsequently been found; and Krüger (8), who failed to find any in a large series of amber Neuroptera, concluded that Berendt erroneously determined the taxonomic position of his specimen. Andrä (1) described and figured a fossil from the Miocene of Steiermark, Austria, which he considered to be a *Chrysopa*, but his illustration clearly shows that the specimen was not a chrysopid, as Scudder, Hagen, and Pongraçz have already stated.

The Florissant species were placed by Scudder in two genera, *Palaeochrysa* and *Tribochrysa*. *Palaeochrysa*

[1] Manuscript received January 12, 1934.

was based upon a single specimen in which all four wings were preserved, but the latter rested one upon the other in such a manner that the veins of a single wing could not be satisfactorily traced. Scudder himself stated that the wings formed a "medley of veins" which were very difficult to disentangle and interpret. He attempted to decipher the venation by means of a photograph on which he traced the veins with ink. This photograph is now in the Museum of Comparative Zoology, and I am convinced from my examination of it that the tracing of the veins was not very successful. Scudder himself pointed out that the published drawing based on this photograph was not correct in several important features, such as the presence of the "double cubital" cell. However, the main diagnostic characteristic of the genus which Scudder mentions in the text, the smooth curve formed by the pseudomedia (upper cubitus of Scudder's terminology) and the inner gradate veins, is discernible in the fossil and is unquestionably valid.

The second genus, *Tribochrysa*, included three species, *inaequalis* (genotype), *firmata*, and *vetuscula*. Scudder designated as the chief characteristic of this genus the abrupt break just beyond the middle of the wing in the curve formed by the pseudomedia and the inner gradate veins, the latter being much nearer than the pseudomedia to the radial sector.

Cockerell has subsequently described (6, 7) four more species of Chrysopidae from Florissant, all of which he placed in *Palaeochrysa;* and he has also shown that Scudder's *vetuscula*, the wings of which were only partially known to Scudder, was really a member of *Palaeochrysa*. In his latest paper on these fossils (7) Cockerell concluded that *Palaeochrysa* is identical with the recent genus *Allochrysa* Banks (2). However, a few years later Navas (10) correctly pointed out that the genus *Allochrysa* Banks is identical with *Leucochrysa* McLachlan (9).[2] Consequently, if we accept Cockerell's view that *Allochrysa* and *Palaeochrysa* are the same, then *Palaeochrysa* is synonymous with *Leucochrysa*, the latter name having priority. As I shall show later, however, *Palaeochrysa* is really very different from *Leucochrysa* and all other existing genera.

## THE VENATION OF THE CHRYSOPIDAE

The general nature of the chrysopid venation and the homology of the venation has been thoroughly studied by Tillyard (11) and need not be discussed here; but I wish to call attention to certain features of the venation which have played an important part in the evolution of these insects and which are of great significance in the taxonomy of the Tertiary and Recent species. One of these is the structure of the basal part of $M_{3+4}$ in the fore wing. In the Recent Chrysopidae there has been an increasing tendency for this vein to loop upwards directly after its

[2] Navas also showed that the genus which Banks had regarded as *Leucochrysa* was not *Leucochrysa* of McLachlan but a different genus, for which Navas established the name *Nodita*.

origin and to coalesce for a short distance with $M_{1+2}$; this much has been demonstrated by the examination of the pupal wing. In many species this looping of $M_{3+4}$ is only half completed, whereas in others the coalescence has become so advanced that $M_{1+2}$ and $M_{3+4}$ are fused for some distance beyond the point at which they normally separate. In a series of chrysopid genera, such as illustrated in figure 8, it is possible to trace the evolution of this area of the wing. The form of the first intra-median cell and the cell below it (*im*, *m*) is not always constant in any one genus or species, however, The condition represented in fig. 8*b*, for example, is the usual one in *Nothochrysa*, but an exact duplication of this formation is occasionally encountered as an individual variation in *Chrysopa*.[3] In the specimens of the South American *Nadiva panchlora* (Gerst.) in the Museum of Comparative Zoology, $M_{3+4}$ exhibits a series of modifications extending from that illustrated in fig. 8*b* to that depicted in fig. 8*d*, not only in different individuals, but in the right and left wings of the same specimens. In *Nodita* the shape of the first intra-median cell is also variable, although the normal condition is of the form shown in fig. 8*c*. In spite of this variability, however, it seems clear that the main line of the evolution of the fore wing in the Chrysopidae has been the reduction and finally the loss of the first intra-median cell, although the form of this cell is not constant in any one genus or species, and cannot, therefore, be considered a hard-and-fast diagnostic characteristic. The fossil Chrysopidae, as I shall show later, demonstrate that as the first intra-median cell has decreased in size, the origin of *Rs* in the fore wing has migrated distally, so that whereas in the more primitive genera *Rs* originates proximad of the separation of $M_{1+2}$ and $M_{3+4}$, in the highly specialized genera it arises either directly above or distad of this separation.

Another structural feature which is of much significance in the phylogeny of the Chrysopidae is the formation of $M_{1+2}$ in the hind wing. $M_{3+4}$ is not looped towards $M_{1+2}$, but the latter is coalesced for quite a distance with the basal part of the radial sector. In all the known existing Chrysopidae this fusion has already been attained, so that $M_{1+2}$ appears to be a branch of *Rs*, although in the nymphal wing the true origin of this vein can be distinguished (see Tillyard (11, Pl. 10). In the various Recent genera of Chrysopidae, however, there is a gradating series extending from the very slight coalescence in *Nothochrysa* (fig. 9*c*) to the much greater fusion in *Chrysopa*. As in the case of the fore wing just discussed, the amount of fusion between *Rs* and $M_{1+2}$ in the hind wing is apparently not rigid in every species and may not even be restricted to narrow limits in the genera; but it is nevertheless of much importance in the phylogeny of the Chrysopidae. The hind wings of the

[3] A specimen of *Chrysopa oculata* Say with the first intra-median cell nearly equal to the median cell below it was described by McGillvray as *Nothochrysa annulata*. (*Can. Ent.*, pp. 169–171, 1894).

fossil species of the family have remained virtually unknown. Scudder attempted to decipher the venation of the hind wings of the type of *Palaeochrysa vetuscula*, but was unable to make anything out of the basal portion. Cockerell published a figure of a very small part of the hind wing of *Palaeochrysa concinnula*, but the veins shown were so different from those of recent species that it was not possible to ascertain from the figure just what portion of the wing was included. The new Creede fossil, however, has one hind wing perfectly preserved, and the specimen of *Palaeochrysa stricta* (*vetuscula*) which Professor Cockerell sent me shows the venation of the hind wing with perfect clearness. Also, the type of *Palaeochrysa wickhami*, loaned to me by Professor Wickham, has the important areas of the hind wing preserved. These fossils show that whereas in some of the genera of Tertiary chrysopids $M_{1+2}$ of the hind wings had already begun to coalesce with *Rs*, in others it was an entirely free vein and in a much less specialized form than the corresponding trachea in the nymphal wing of the Recent species.

For reasons which will be given more fully below, I believe that three genera are required for the reception of the known fossil species. They can easily be distinguished as follows:

1. The inner gradate veins (*g*) forming a smooth curve, continuing the line of the pseudomedia (*M'*).....2
1. The inner gradate veins higher than the end of the pseudomedia and hence not continuing the curve of the pseudomedia .....*Tribochrysa*
2. *Rs* of fore wing arising far proximad of the fork of the media into $M_{1+2}$ and $M_{3+4}$; $M_{1+2}$ of hind wing entirely free from *Rs* .....*Palaeochrysa*
2. *Rs* of fore wing arising at a point very nearly above the fork of the media into $M_{1+2}$ and $M_{3+4}$; $M_{1+2}$ of hind wing coalesced with *Rs*.....*Lithochrysa*, n. gen.

## SYSTEMATIC DESCRIPTIONS

### Genus PALAEOCHRYSA Scudder

SCUDDER, *1890*, U. S. Geol. Geogr. Survey Terr., Rept., vol. 13, p. 166.
COCKERELL, *1908*, Can. Ent., vol. 40, p. 90.

Fore wing: costal space moderately widened about as in *Chrysopa; Rs* arising far proximad of the fork of the media into $M_{1+2}$ and $M_{3+4}$; first intra-median cell and median cell below it subequal, the dividing part of $M_{3+4}$ being parallel to the longitudinal axis of the cells; the inner gradate veins (*g*) placed at the same level as the pseudomedia, continuing the curve of the pseudomedia; outer gradate veins similarly continuing the smooth curve of the pseudocubitus.

Hind wing: costal space not widened; inner and outer gradate veins as in the fore wing; *Rs* arising proximad of the separation of the veins $M_{1+2}$ and $M_{3+4}$; $M_{1+2}$ free from *Rs*; $Cu_1$ not coalesced with the media.

Antennae somewhat shorter than the wings; head and rest of body as in the Recent Chrysopidae.

Genotype: *Palaeochrysa stricta* Scudder.

In this genus the wings were less specialized than those of any other known chrysopids, as evinced by the early origin of *Rs* in the fore wing and the independence of $M_{1+2}$ in the hind wing. The three known species of the genus can be separated by the following key:

1. Anterior branch of 1*A* in the fore wing not coalesced with $Cu_2$..... .....*fracta* Cockerell (Florissant)
1. Anterior branch of 1*A* in fore wing coa-

lesced with $Cu_2$.....2

2. Basal Banksian cell (*b*) of hind wing very long.....*creedei*, n. sp. (Creede)

2. Basal Banksian cell of hind wing of moderate size.....*stricta* Scudder (Florissant)

PALAEOCHRYSA STRICTA Scudder

Figure 1

*Palaeochrysa stricta* SCUDDER, *1890*, U. S. Geol. Geogr. Survey Terr., Rept., vol. 13, p. 166, pl. 14, figs. 13, 14.

*Tribochrysa vetuscula* SCUDDER, *Idem.*, p. 170, pl. 14, fig. 9.

*Palaeochrysa vetuscula* COCKERELL, *1908*, Can. Ent., vol. 40, p. 90.

Fore wing: length, 14.6 mm.–15 mm.; width, 5.2–5.5 mm.; about 19 cross-veins between $R_1$ and *Rs;* inner and outer gradate veins equal in number; about 10 unbranched veinlets between pseudocubitus and hind margin; anterior branch of 1*A* coalesced with $Cu_2$ for a short distance; basal Banksian cell (*b*) of moderate length only. Hind wing: length, 13 mm.; width, 4.5 mm.; about 16 cross-veins between $R_1$ and *Rs;* basal Banksian cell of moderate length; all veins terminating on the hind margin are forked, except those at the very apex and $Cu_1c$.

Holotype: Mus. Comp. Zool. (Harvard Univ.) 242ab; Florissant, Colorado (S. H. Scudder).

As I have already stated, the type specimen is poorly preserved, all four wings being overlapped. The above description has been drawn up from an excellent specimen consisting of a fore and a hind wing, which was collected in the Florissant shales by Mrs. Cockerell and loaned to me by the Museum of the University of Colorado. This is the same fossil as that which Cockerell mentioned (5, p. 90) under the name of *Palaeochrysa vetuscula* Scudder. The latter species was known to Scudder only from an incomplete specimen and was placed by him in *Tribochrysa*, as pointed out by Cockerell, who transferred it to *Palaeochrysa* and also suggested the possibility of its being conspecific with *stricta*. Having both the type of the latter and Cockerell's fossil at hand I have been able to compare them and am convinced that this synony

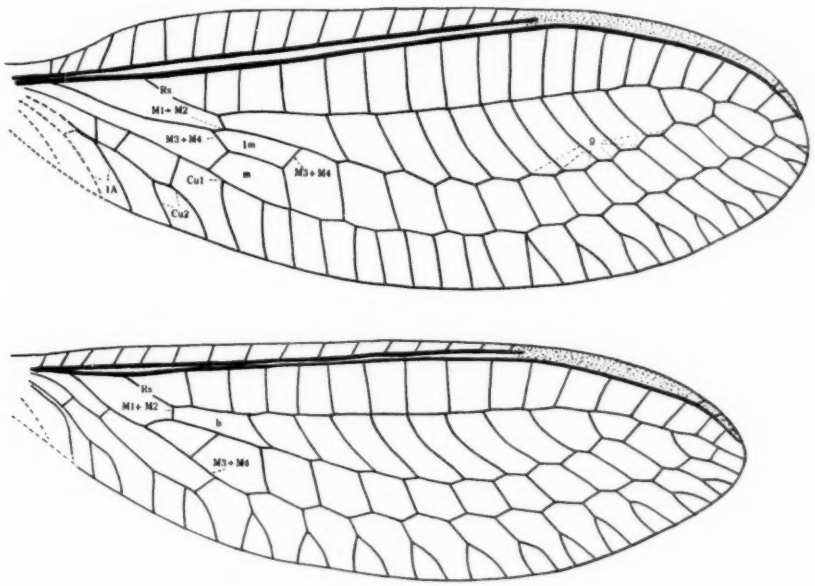


FIG. 1. Fore and hind wings of *Palaeochrysa stricta* Scudder; drawing based on specimen in the University of Colorado Museum.

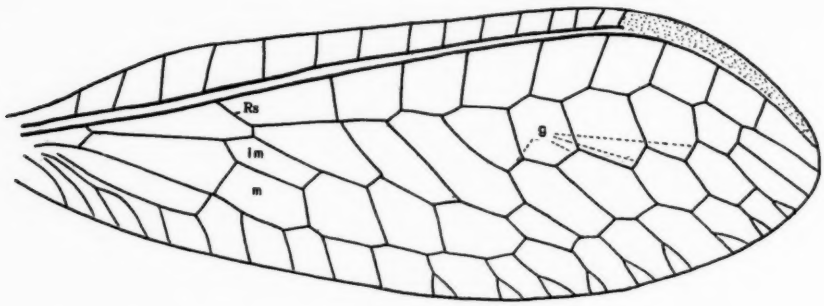


FIG. 2. Fore wing of *Palaeochrysa fracta* Cockerell; drawn from holotype.

my is a fact, the name *stricta* having the priority.

PALAEOCHRYSA FRACTA Cockerell
Figure 2

*Palaeochrysa fracta* COCKERELL, *1914*, Jour. Geol., vol. 22, p. 716, fig. 2.

Fore wing: length, 17 mm.; width, 11 mm.; about 19 cross veins between $R_1$ and *Rs;* inner and outer gradate veins equal in number; basal part of $M_{1+2}$ very close to *Rs;* basal Banksian cell (*b*) of moderate length; 8 unbranched veinlets between pseudocubitus and hind margin; 1*A* entirely free from $Cu_2$. Hind wing unknown.

Holotype: Mus. Comp. Zool. (Harvard Univ.) no. 3349; recently donated to the Museum by H. F. Wickham, who collected it at Florissant, Colorado. The type specimen consists of a finely preserved fore wing, complete except for the very base of the wing.

This species is very close to *stricta*. The difference in the shape of the first intramedian cell mentioned by Cockerell is probably only an individual variation; but the independence of the anterior branch of 1*A* from $Cu_2$, which are coalesced in the other species of the genus, is certainly a specific feature, and the smaller number of unbranched veins leading from the pseudocubitus to the hind margin may also be in that category.

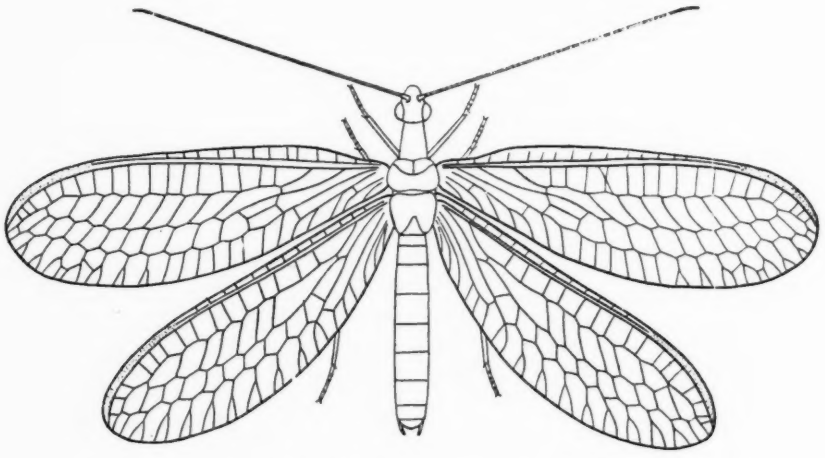

FIG. 3. *Palaeochrysa creedei* Carpenter, n. sp.; drawn from holotype.

PALAEOCHRYSA CREEDEI Carpenter, n. sp.
Figure 3

Fore wing: length, 13 mm.; width, 4 mm.; costal space not quite so wide as in *stricta*, and the apex of the wing is more rounded; about 17 cross-veins between $R_1$ and *Rs;* inner and outer gradate veins equal in number; 8 unbranched veins between the pseudocubitus and the hind margin; basal Banksian cell long. Hind wing: length, 11 mm.; width, 3.7 mm.; about 15 cross-veins between $R_1$ and *Rs;* veins terminating on hind margin as in *stricta;* the basal Banksian cell (*b*) very long. Length of body, 12 mm.; antennae, 9 mm.

Holotype: Mus. Comp. Zool. (Harvard Univ.) no. 4316ab; collected by Allan Caplan in the Miocene shales of Creede, Colorado, 1932.[4] This fossil is very well preserved. The two right wings are outspread as shown in figure 3, but the left fore wing overlies the hind wing. The body is unusually clear, showing even the tarsal segmentation of the fore legs, the segmentation of the antennae and the detailed structure of the thorax. The prothorax is quite long, much more so than in the type of *P. stricta*. The head of the fossil is somewhat more rounded than it is in the existing chrysopids, but shows obvious signs of having been flattened and crushed during the process of preservation, as do many of the Florissant insects.[5] In figure 3 I have drawn the head as it undoubtedly was in the living insects and as it is preserved in the type of *stricta*. The eyes are prominent and placed on the head just as in Recent chrysopids.

[4] This is the second insect to be described from the Creede beds. The geology of this formation has been treated in Emmons and Larsen, Geology and ore deposits of the Creede district, Colorado: *U. S. Geol. Survey, Bull.* 718, 1923. A small collection of plants was studied by F. H. Knowlton, Fossil plants of south-central Colorado: *U. S. Geol. Survey, Prof. Paper* 131-G, 1923, who concluded that the deposit was about the same in age as the Florissant shales.

[5] I have discussed the indications of this flattening in the Fossil ants of North America: *Mus. Comp. Zool., Bull.* 70, 1930.

This species is close to the two insects just described, but can readily be distinguished by the longer basal Banksian cell of the fore and hind wings.

LITHOCHRYSA Carpenter, n. gen.

Fore wing: costal space about as wide as in *Palaeochrysa; Rs* arising almost over the division of the media into $M_{1+2}$ and $M_{3+4}$; first intra-median cell and median cell below it subequal, the dividing part of $M_{3+4}$ being parallel to the longitudinal axis of the cells; inner gradate veins (*g*) placed at the same level as the pseudomedia (*m'*) and continuing the curve of the pseudomedia; outer gradate veins similarly continuing the curve of the pseudocubitus.

Hind wing: costal space not widened; inner and outer gradate veins as in fore wing; *Rs* arising slightly proximad of the division of *M* into $M_{1+2}$ and $M_{3+4}$; $M_{1+2}$ coalesced with *Rs* for a short distance. The cross-veins in both pairs of wings are much less numerous than in *Palaeochrysa*.

The general habitus of the body is similar to that of *Palaeochrysa*.

Genotype: *Palaeochrysa wickhami* (Cockerell).

LITHOCHRYSA WICKHAMI (Cockerell)
Figure 4

*Palaeochrysa wickhami* COCKERELL, *1914*, Jour. Geol., vol. 22, p. 717, fig. 3.

Fore wing: length of preserved portion, 18 mm.; estimate of whole length, 20 mm.; width, 6 mm.; about 9 cross-veins between $R_1$ and *Rs;* inner and outer gradate veins equal in number; 6 unbranched veins leading from pseudocubitus to the hind margin; anterior branch of 1*A* coalesced with $Cu_2$. Hind wing: length, 18 mm.; width, 5 mm.; about 10 cross-veins between $R_1$ and *Rs;* basal and central portions of the wing unknown.

Length of body including head, 8 mm.

Holotype: Mus. Comp. Zool. (Harvard Univ.) no. 3350; recently donated to the Museum by H. F. Wickham, who collected it at Florissant, Colorado.

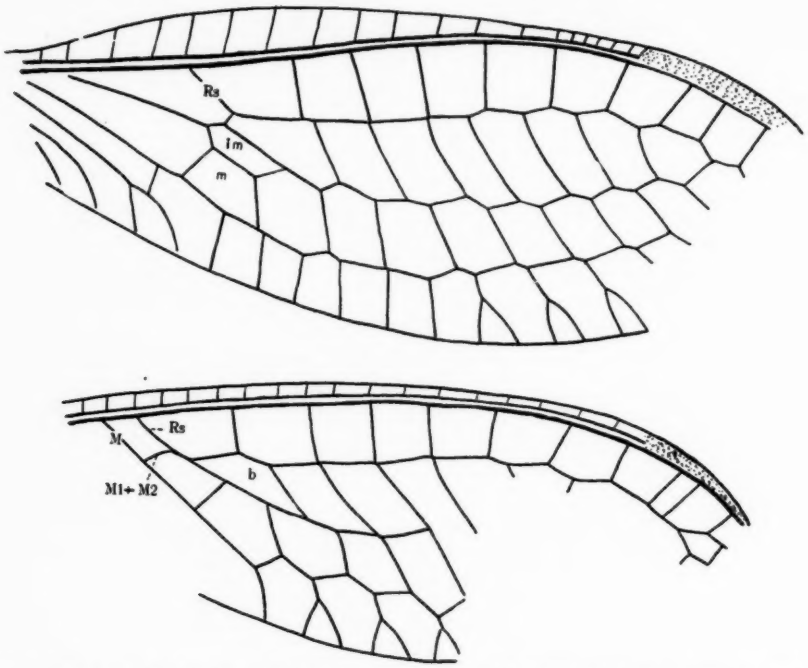


FIG. 4. Fore and hind wing of *Lithochrysa wickhami* (Cockerell); drawn from holotype.

The type specimen consists of a more or less complete insect, though the antennae are not entirely preserved and the legs are missing. The fore wing of each side lies over the hind wing, but the angles at which the wings rest are such that nearly the whole fore wing can be distinguished and also the important parts of the hind wing.

LITHOCHRYSA CONCINNULA (Cockerell)
Figure 5

*Palaeochrysa concinnula* COCKERELL, *1909*, Can. Ent., vol. 41, p. 218, fig. 5.
*Palaeochrysa ferruginea* COCKERELL, idem., p. 218, fig. 6.

Fore wing: length, about 12 mm.; 8 cross-veins between $R_1$ and *Rs;* inner and outer gradate veins equal in number. According to Cockerell only a small part of the hind wing is preserved, but this shows the basal region, including the origin of $M_{1+2}$.

Holotype: Mus. Univ. Colorado, Boulder; collected at Florissant, Colorado.

I have not been able to see the type of this insect, but Professor Cockerell, to to whom I wrote regarding certain features of the wing, states that nothing is visible except what he has already described or figured. It is possible that this insect is identical with the previous species; the fore wing is 2 mm. longer than that of *wickhami*, but that difference is

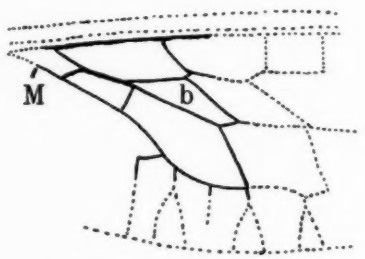


Fig. 5. Base of hind wing of *Lithochrysa concinnula* (Cockerell); solid portion of figure taken from Cockerell (6). The broken lines have been added to enable comparison with fig. 4.

well within the limits of variation in size attained by Recent species of the family. I believe that *ferruginea* Cockerell is synonymous with *concinnula*, although I have not seen the type of that species either, it also being in the University of Colorado Museum. The type specimen, which consists of a fore wing, is apparently poorly preserved, for Professor Cockerell writes me that he has described and figured all that can be seen in the fossil. The wing is only 0.5 mm. shorter than that of *concinnula*, and the venation is apparently the same except for structures which can only be regarded as individual variations. Cockerell states in his description that the "venation" is ferruginous, but since that is true of all the fossil chrysopids which I have seen, I do not consider it a specific characteristic.

Genus TRIBOCHRYSA Scudder

*Tribochrysa* SCUDDER, *1890*, U. S. Geol. Geogr. Survey Terr., Rept., vol. 13, p. 168.

Fore wing: costal space moderately widened, about as in *Palaeochrysa; Rs* arising only very slightly proximad of the separation of the two main branches of *M;* first intra-median cell much narrower than the median cell below it; inner gradate 8, nearer to *Rs* than to the level of the pseudomedia (*M'*), hence not continuing the course of the latter; cross-veins about as numerous as in *Lithochrysa*. Hind wing unknown.

The antennae are somewhat shorter than the wings and the body as a whole resembles that of the Recent Chrysopidae.

TRIBOCHRYSA INAEQUALIS Scudder

Figure 6

*Tribochrysa inaequalis* SCUDDER, *1885*, in Zittel, Handb. Palaeont., vol. 1, p. 777, fig. 982.—SCUDDER, *1890*, U. S. Geol. Geogr. Survey Terr., Rept., vol. 13, p. 170. —COCKERELL, *1908*, Can. Ent., vol. 40, p. 90.

Fore wing: length, 12.5 mm.; width, 4.5 mm.; 9 or 10 cross-veins between $R_1$ and *Rs;* inner and outer gradate veins 7 or 8; 5–6 unbranched veinlets between pseudocubitus and hind margin; anterior branch of $1A$ coalesced with $Cu_2$.

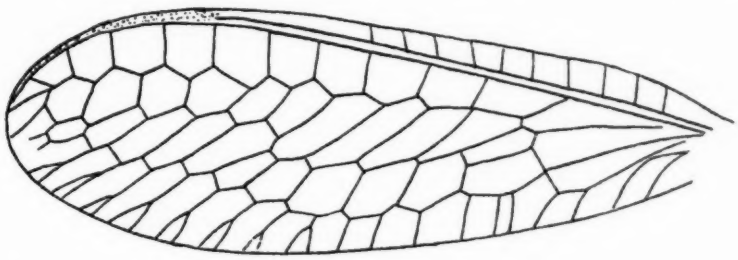

FIG. 6. Fore wing of *Tribochrysa inaequalis* Scudder; drawn from holotype.

Holotype: Mus. Comp. Zool. (Harvard Univ.) no. 243; Florissant, Colorado. This specimen consists of a more or less whole specimen, though the venation of one fore wing is all that can be discerned clearly.

TRIBOCHRYSA FIRMATA Scudder

Figure 7

*Tribochrysa firmata* SCUDDER, *1890*, U. S. Geol. Geogr. Survey Terr., Rept., vol. 13, p. 172, figs. 6, 7, 10, 11.

Fore wing: length, 10–11 mm.; width, 3.5 mm.; 8 cross-veins between $R_1$ and *Rs;* 6 or 7 inner and outer gradate veins; 4 unbranched veinlets between pseudocubitus and hind margin; anterior branch of $1A$ coalesced with $Cu_2$.

Cotypes: Mus. Comp. Zool. (Harvard Univ.) no. 241 (Scudder's no. 670) and no. 4127, (Scudder's no. 8792); Florissant, Colorado. The former specimen,

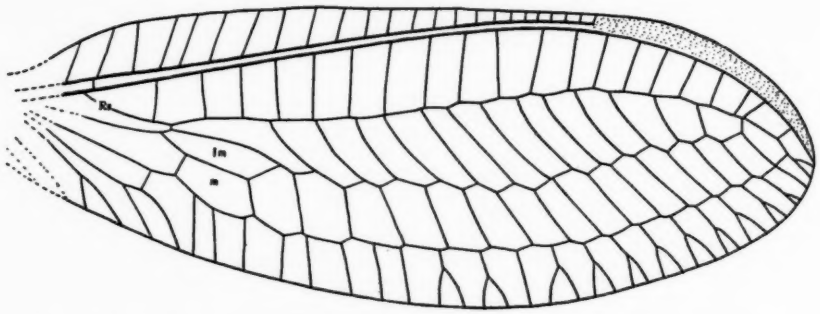


FIG. 7. Fore wing of *Tribochrysa firmata* Scudder; drawn from cotype no. 241.

consisting of a whole insect, is the better of the two; it shows the venation of one fore wing clearly, but the other wings are twisted and distorted to such an extent that the veins cannot be distinguished. The second specimen is a lateral view of the insect, with all four wings overlapped.

*Firmata* is close to *inaequalis*, but apparently deserves specific distinction. It can be separated by the smaller number of closed cells in the wing as a whole, there being about 62 of these in *inaequalis* and 52 in *firmata*.

## EVOLUTION OF THE CHRYSOPIDAE

The Tertiary Chrysopidae, although few in number and known only from one geological period, have contributed enough data to enable us to form some conception of the evolution of these insects since the middle of the Tertiary. It is obvious that although the body structure has apparently undergone no modifications since the Miocene, the wings have

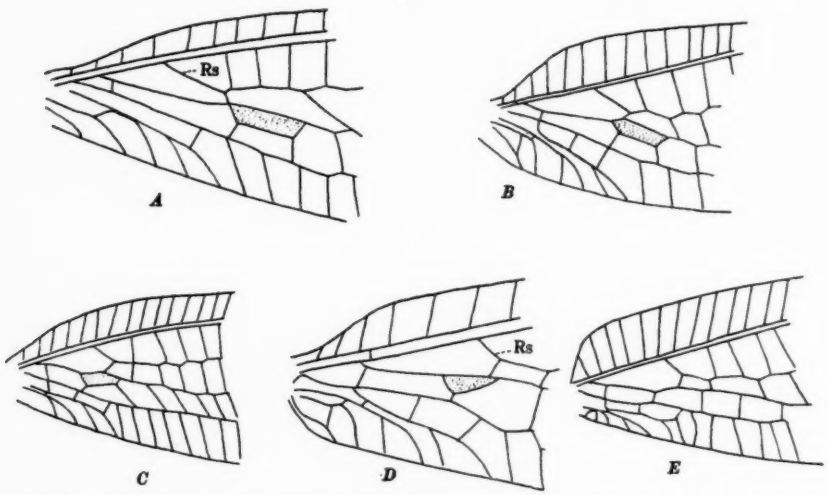


FIG. 8. Evolution of the basal part of the fore wing of the Chrysopidae. *A*, *Palaeochrysa creedei* Carpenter, n. sp.; *B*, *Nothochrysa californica* Banks; *C*, *Nodita pavida* Hagen; *D*, *Chrysopa signata* Walker (after Tillyard); *E*, *Sencera anomala* Brauer. The first intra-median cell has been shaded to enable easy comparison,

passed through a series of salient changes. Four of these alterations are especially noteworthy:

1. In all the Tertiary species now known $M_{3+4}$ of the fore wing is formed as in the least specialized of the Recent chrysopids; that is, the first intra-median cell is subequal to the median cell below it. The greater reduction of the first cell, formed by the more prompt looping of $M_{3+4}$ towards $M_{1+2}$ and characteristic of by far the majority of the existing Chrysopidae (*Chrysopa*, *Nodita*, etc.), is apparently a specialization which has been developed since the middle of the Tertiary (see figure 8).

2. In *Palaeochrysa* the radial sector originates near the base of the fore wing, far proximad of the basal end of the first intra-median cell. In the other Tertiary genera, *Tribochrysa* and *Lithochrysa*, the origin of *Rs* is about at the same level as the proximal end of the first intra-median cell. But with the exception of the single genus *Nothochrysa*, in all existing Chrysopidae the radial sector arises distad of the base of the first intra-median cell. In certain species of *Nothochrysa* (and I believe that the genus should be restricted to these species) the radial sector originates a little proximad of the base of first intra-median cell. Apparently, then, the origin of *Rs* in the fore wing has tended to migrate distally since the Miocene, *Nothochrysa* being

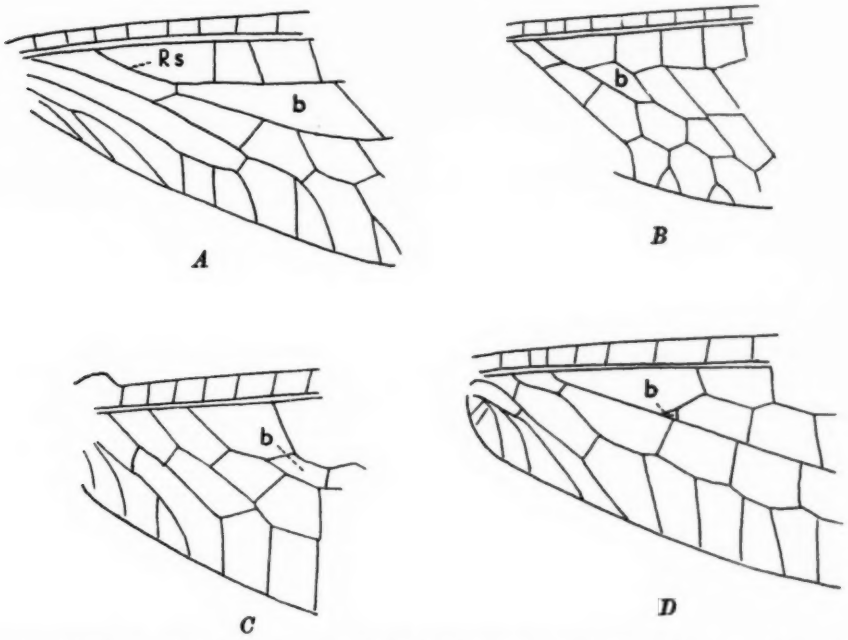


FIG. 9. Evolution of the proximal part of the hind wing of the Chrysopidae. *A*, *Palaeochrysa creedei* Carpenter, n. sp.; *B*, *Lithochrysa wickhami* (Cockerell); *C*, *Nothochrysa californica* Banks; *D*, *Chrysopa signata* Walker (after Tillyard). *Rs*, radial sector; *b*, basal Banksian cell.

the only genus which still retains the condition present in the Middle Tertiary.

3. A particularly striking feature of the chrysopid wings, both fore and nind, which has also been perfected in the later Tertiary and Pleistocene, is the pseudomedia and to a somewhat smaller extent the pseudocubitus. In *Palaeochrysa* and *Lithochrysa* there is no break or line of demarcation between the pseudomedia and the inner gradate veins. In *Tribochrysa*, however, the pseudo-media is at a lower level than the gradate veins, so that there is a distinct break in the curve which in *Palaeochrysa* was formed by these two series of veins. Even in *Tribochrysa*, however, the pseudomedia was distinctly "zigzagged." In all Recent chrysopids the line of separation between the pseudomedia and inner gradate veins is very plain, due mainly to the straightening of the pseudomedia. In *Chrysopa*, for example, the latter is in the form of a straight line.

4. The most interesting of all the modifications is the coalescence of the proximal part of $M_{1+2}$ with *Rs* in the hind wing (fig. 9). In *Palaeochrysa* these veins are entirely independent of each other; in the Tertiary *Lithochrysa* and the Recent *Nothochrysa* $M_{1+2}$ is coalesced with *Rs* for a very short space only. But in all other Recent Chrysopidae $M_{1+2}$ is fused with *Rs* for a considerable distance. This increasing coalescence of these two veins has greatly affected the form of the basal Banksian cell (*b*): in *Lithochrysa* it is almost as large as in *Palaeochrysa;* in *Nothochrysa* it is about half the size as in *Lithochrysa;* and in the other Recent members of the family it is reduced to a small triangle which is hardly perceptible, or is completely absent.

These modifications of the wings of the Chrysopidae, which have occurred since the Miocene in spite of the stability of the body structure, are especially interesting in view of the similar history of the Mecoptera; for as I have already shown (4) the Miocene Mecoptera had as complete and specialized a body structure as the Recent members of the order, although their wing structure was almost identical with that of the Mesozoic (Jurassic) species. As a consequence of the differences between the wings of the Tertiary and Recent representatives of the Mecoptera and Chrysopidae, all of our existing genera were apparently evolved since the Miocene. This is a striking contrast to the condition presented by certain other groups of insects, such as the ants and caddis-flies, of which more than half of the mid-Tertiary genera are still extant.

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# THE ECOLOGY OF SAND AREAS[1]

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ABSTRACT

Sand areas of today are either areas where new deposits are being made in sufficient amount to bury the original surface, or areas where new deposition is scant and the old deposits are subjected to reworking. Five environments may contain sand areas—an area of aeolian deposition, an alluvial fan, a lake or sea shore, an area of stream deposition, and a lake or sea bottom. Each of these is considered in turn and the character of the final deposits estimated.

The problem of the ecology of sand areas may be studied on areas where sands are now in process of deposition, or the conditions of environment may be deduced from studies of ancient deposits of sands, of which each bedding or lamination plane was at one time the surface. The conditions may be observed on existing sand areas and the facts obtained, but in ancient deposits the conditions must be inferred and opinions instead of facts are acquired.

Recent or existing sand areas may be placed in two general classes; one on which from time to time deposits of sand are made in quantities sufficient to bury the original surface, and another with contributions so scant that the sands covering the area are subjected to repeated deposition. The first condition subjects the inhabitants on the area to the hazards of sudden burial. The inhabitants on the latter area live under the difficulties of great instability of the substratum. There are, of course, all intermediate stages.

Sand areas may exist in any of the following general environments: area of eolian deposition, an alluvial fan, lake or sea shore, area of stream deposition, and lake or sea bottom. These five environments differ in their inhabitants both qualitatively and quantitatively, but the materials upon, or in which the inhabitants live and in which their preservable remains may be entombed differ little in composition and structure except as the structure is a consequence of eolian or aquatic deposition.[2] Each environment has a range in rate of deposition from one so slow that the deposits made during a year may be measured in fractions of millimeters, or there may be no deposits at all, to the other extreme where sands are deposited at the rate of inches or even feet per week. The variation in

[1] This paper was contributed to a symposium on paleoecology held at the meeting of the Paleontological Society in December, 1933. Manuscript received February 8, 1934.

[2] Case, E. C., The environment of vertebrate life in the late Paleozoic in North America: *Carnegie Inst. Wash., Publ.* 283, p. 43, 1919.

the rate of deposition has important consequences with respect to the variety and quantity of population, the preservation of the organic matter after the death of an organism, and the possibility of transportation into the area of organic matter from other environments. The environments of the river, lake and sea bottoms, and lake and sea shore have large possibilities of becoming burial places of planktonic, nektonic, and benthonic animals that dwell in the overlying or adjacent waters. In most instances the incorporation of the remains of nektonic and planktonic organisms is not great in river waters, it has some importance on lake shores and bottoms, and is of great importance on sand areas adjacent to or beneath the sea. An aqueous environments may receive drifted matter from the land.

All sands are permeable, and removal of soluble material is always possible before the sands are buried beneath other sediments, and again becomes possible when the sands or sandstones are raised above sea level and are subjected to the influence of active underground water circulation.

The ecology of the five general environments listed above will be examined from the stratigraphic and sedimentary points of view in the paragraphs that follow.

### THE ENVIRONMENT OF A SAND AREA OF EOLIAN DEPOSITION

A sand area of eolian deposition is a dune area in an arid region or adjacent to a body of water. In an arid region there is a small population of a few species of animals and plants. The plants have zerophytic characters with leaves and stems adapted to permit the minimum of transpiration and with roots adjusted to a deep water table or to a limited seasonal precipitation. Many plants are spiny. The animals consist largely of insects, pulmonate gastropods, lizards, snakes, rodents, a few other herbivorous mammals, some birds, and some of the small and medium-sized predators.[3] Should these animals die where the rate of deposition is slow, the remains must be left on the surface for a considerable period of time and long before burial ordinarily is possible the remains may have totally disappeared. Nothing may remain to serve the stratigrapher, the sedimentationist, and the paleontologist. Should deposition be so rapid that the organisms are buried either dead or alive beneath a considerable thickness of drifting sand, the remains may persist; but the possibilities of destruction through later exhumation, or because of solution, are very real.

If the sand areas are dunes connected with a river, a lake, or the sea, considerable moisture is probable. Such regions usually are limited in area and thus are apt to be greatly influenced by the conditions and organisms of surrounding areas and these organisms may make permanent homes over parts of the dune area, wander in periodically or occasionally, and, in the cases of plants,

[3] Bailey, Vernon, Dwellers in the desert: *Nature Mag.* vol. 23, p. 63, 1934.

there is strong possibility of leaves being brought in by the wind. The sands of dune areas of this kind are derived from the waters in which the sands were produced and there may also be brought from the same sources other productions of the bodies of water. Thus oolites may be brought by winds from the shores of the sea or a lake, as is now being done on the shores of Great Salt Lake; shells of Protozoa and other small animals as at Dog Bay in Ireland, and broken up shell matter as on Bermuda and at many other places. Thus sand areas of eolian deposition may contain a thanatocoenosic assemblage of organisms of considerable complexity. As there is plenty of moisture in dune areas connected with bodies of water the water table in the sand deposits may be high, thus perhaps leading to ready cementation of the sands and thus some remains of the buried organisms may persist.

### THE ENVIRONMENT OF A SAND AREA ON AN ALLUVIAL FAN

The environment of the alluvial fan is that of the land, but the deposition of the composing materials is mostly done by aqueous agencies, although there is a probability that some deposition may be eolian, since sands deposited by water may become dry and then be picked up by wind and redeposited. The sands tend to be dirty with clay and silt, thus decreasing the perviousness and the possibility of the removal of buried organic matter by solution. The deposits differ from those of a dune area in that periodically they are soaked with water and the water table may be relatively high over part of the area. Deposition may, and is likely to be, quite rapid, which restricts the quantity of vegetation, and as the best development of alluvial fans is in an arid region the climatic conditions tend to the same effect. The restriction of vegetation has as a corollary restriction of animals. Organisms over an alluvial fan tend to be like those of adjacent areas, but there is a much better chance for preservation, in general, than in adjacent areas.

Another factor obtains on some alluvial fans that is worthy of consideration. When a fan is not receiving sufficient water to bring the water table close to the surface there may be rise of moisture through capillary action and deposition of materials in solution on evaporation of this moisture, and this deposition may aid in the preservation of organic remains.

Sands deposited in the alluvial fan environment seem to be illustrated in the ancient deposits in parts of the Old Red Sandstone of the British Isles, parts of the Newark series of the Appalachian Piedmont, some of the Mississippian sandstones of the Appalachian region,[4] and there are important deposits in the Great Plains Tertiary.

### THE ENVIRONMENT OF A SAND AREA OF STREAM DEPOSITION

River sand areas may be those of shifting sands with small contribu-

[4] Barrell, J., Origin and significance of the Mauch Chunk shale: *Geol. Soc. Am., Bull.*, vol. 18, pp. 449–476, 1907.

tions of sand, or areas receiving large additions. In the latter case the bottoms may be built to, or even above, the average surface of the stream.

River bottoms with shifting sands and limited contributions are at about the profile of equilibrium at the place, and such bottoms offer little favoring colonization by organisms. Aquatic plants may have slight development and with these will come animals to feed upon them. Aquatic mollusks may be brought by floods, but these are likely to remain only until they can travel into more congenial waters. Small animals may dwell in the sands a short distance beneath the surface. Few of the remains attaining the surface of the sand area have a chance of preservation, as the conditions are very adverse to burial, upon which factor preservation altogether depends.

River sand areas receiving large additions of sands are usually in the form of bars that during the flood season may be built above normal water level, so that with falling water the upper surface becomes exposed. The conditions do not favor colonization by aquatic organisms. During times of high water, migration to the bars may be forced. Aquatic plants may be torn from their natural habitats, drift to the bars and take root, or seeds may be brought and germinate there. The plants may serve to anchor the bar, and they may catch sediments if the surface is below water and thus ultimately build it above normal water level. Seeds of land plants may then be brought, either by water or wind, and these may germinate and grow. Grier and Tweedy[5] note the common presence on the bars of the upper Mississippi of five species of aquatic plants. Plants above water attract insects and these may attach their egg cases and larvae to the plants. Crustaceans and other animals of the stream may come to feed upon the plants, or the animals. Because of the shallowness of the water over submerged bars tadpoles are likely to live about them, and these may also be found in pools on exposed bars. Crayfish wander over exposed and submerged bars, but commonly do not make "castles" unless there is considerable mud in the sands. Floods may bring mussels, torn loose from congenial waters up stream. Most of these seem to be young individuals. They may be buried in the sands or be deposited on the surface, and if the bar becomes exposed they may die on the surface or burrow into the sands to die later. They may also wander into the bordering waters leaving trails thereto. Grier and Tweedy state that twelve species of pelecypods and four species of gastropods are common on bars in the upper Mississippi, and they state that occasional shells of all the sixty-three species from the upper Mississippi may be found thereon. Sections of bars are said often to show shells in successive layers. Fish hover around bars searching for food or to get into

[5] Grier, N. M., and Tweedy, R. B., The fauna of the sandbars of the upper Mississippi River: *Wagner Free Inst. Sci., Bull.*, vol. 2, no. 6, pp. 97–105, 1927.

shallow water to escape cannibalistic associates, and some of the remains may be found in the deposits. Other animals occasionally found are the mud puppy, frog, toad, and newt of the amphibians; turtles that come to bask in the sun; an occasional snake; aquatic birds seeking food or gravel; and mammals like the muskrat and the raccoon. Any and all of these may leave remains in the sands.

There thus may be entombed in the sands of river bars the remains of aquatic and land plants, crustaceans, pelecypods, gastropods, insects, fish, amphibians, reptiles, birds, and mammals, although few of these organisms maintain a permanent home over sands. The entombed remains constitute a perfect thanatocoenose, but not a biocoenose.

Circulation of water through river sands is always probable unless the sands contain much silt or clay and this water together with carbon dioxide derived from decay of organic matter may lead to complete solution of the hard parts of buried organisms, with little left to indicate the one time presence of numerous individuals. Those who have studied the deposits of river sands are well aware of the general scantiness of organic remains, but also have frequently been pleasantly surprised by an occasional local abundance.

A particular variety of stream sand area is the outwash about the fronts of glaciers. These also partake of the characters of an alluvial fan. However, the environment is not one favoring the presence of organisms and remains are not likely to be entombed. That such, however, has occurred is evidenced by the occasional remains of the mastodon and mammoth found in sands of the Pleistocene.

Ancient deposits of the river sand environment are sandstones in the Pennsylvanian system in the Appalachian, Eastern Interior and Western Interior Coal Basins; channel fillings in the Dakota sandstones of Kansas and other parts of the west; and the Great Plains Tertiary contains sands of this environment.

### THE LAKE OR SEA SHORE ENVIRONMENT OF SAND DEPOSITION

From the points of view of the character of the deposits and the sedimentary structures associated with them there are few differences in the sand areas of the lake and sea shores. The beach zone of the sea, because of the tides, is wider than that of a lake, and the numbers of animals and plants on sea beaches far outnumber those on lake beaches. Few animals and not many plants dwell on lake shore sands, and the organic remains found in these sands are very largely derived from the adjacent land and the lake. At times of fish epidemics, when fish may die by thousands, as happened in Lake Mendota at Madison, Wisconsin, in the summer of 1932, lake shores may become overburdened with dead fish but such occurrences are sporadic and not general. Some lake shores have numerous shells of such gastropods as *Limnaea* and *Planorbis;* but,

in general, the sands of lake shores contain sparse animal and plant remains.

The story is somewhat different on the sand shores of the sea, particularly the warmer seas. The living conditions in and on sea shore sands are difficult, and there are few other habitats in the sea where the influence of the physical conditions is so profound or so obvious.[6] Among these conditions the ebb and flow of the tide and the resulting alternation of exposure are most important. The surface temperature alternates twice daily between that of the sea and that of the air. It has the entire range of seasonal temperature of the air, and if the range leads to very low temperature the elimination of the beach life is probable. The salinity of the interstitial waters of the sands may be increased by evaporation or diluted by fresh waters flowing from the land either through or over the sands, and further dilution may be brought about by rain. Living organisms in the sands, the products of their metabolism, and the decay of organic matter may profoundly modify the gaseous and dissolved content of the waters therein, with disastrous results to the organisms. Some of the bacterial activity may lead to the formation of hydrogen sulphide and ultimately ferrous monosulphide or disulphide, bringing about the black sands sometimes found a short distance beneath the surface, as in the Wash on the east coast of England, Port Erin on the Isle of Man, parts of the shores of the Clyde Estuary, and elsewhere.[7]

Each sand hole in the sands of a beach may be inhabited by a sand hopper or some animal of like habits. Some gastropods, as *Littorina littoria*, may dwell on sand shores; there may be a considerable number of pelecypods, as the little neck clam, *Mya arenaria*; the razor shell clam, *Solen ensis*; the black mussel, *Mytilus edulis*; and certain capulids if there is anything to which these shells may attach themselves. On many shores of the warmer waters myriads of crabs wander about seeking for carrion, or burrow in the sands. The little neck clam and similar sand burrowing organisms live beneath the surface and have splendid possibilities of preservation, as they are already buried should natural death overtake them. The sands may contain numerous small crustaceans and protozoans. In addition there may be introduced from adjacent waters animals and plants of the nekton, plankton, and benthos and there also may be brought a considerable quantity of material derived from the adjacent land. Some of the organic

[6] Bruce, J. R., Physical factors in the sandy beach: *Marine Biol. Assoc., Jour.*, vol. 15(2), pp. 535–565, 1928.

[7] Johnstone, J., On black littoral sands in Lancashire: *Lancashire Sea-Fisheries Lab. Ann. Rept. (for 1920)*, pp. 106–109, 1921.

Ellis, D., An investigation of the causes of blackening of the sands in parts of the Clyde Estuary: *Roy. Tech. Coll. Glasgow, Jour.*, pp. 144–156, 1925.

Kindle, E. M., The intertidal zone of the Wash., England: *Nat. Res. Coun., Rept. Comm. Sedimentation, 1928–1929*, pp. 14–15, 1930.

matter derived from the sea may come in very large quantities, as the heaps or windrows of sea weeds that storms at times sweep from the sea to the beach. This has been observed by the writer on Anticosti Island and other parts of the Gulf of St. Lawrence, where rotting sea weeds have covered sands to a depth of a foot or more over an extent of miles. As each seaweed is the dwelling place for numerous organisms these are brought along and become a part of the organic matter of the shore. The deposits may contain an assemblage of shells and other organic matter that does not give a picture of the life dwelling on the shore at the time the deposit was made, as no, or few, organisms of the assemblage lived where found. The assemblage is a thanatocoenose and not a biocoenose. On existing shores it is not difficult to differentiate the organisms that live on the shore from those that have been brought thereto, but in the geologic column this differentiation is difficult and may not be possible.

Many sandy shores seem to be barren of macroscopic life. There are shores on the north coast of the Gulf of St. Lawrence in the vicinity of the Mingan Islands and on Anticosti that seem to contain essentially nothing of organic origin; there are others that seem to have no indigenous life, but have an abundance of dead organic material brought by the waves of the sea. The bay on the west side of Clearwater Point on the Quebec Coast is commonly covered with numerous sea weeds, large *Mya arenaria*, shells of several other species of pelecypods, a few gastropods, and after every storm in the proper season by myriads of the dead bodies of the small fish known as the caplin; but if these shore sands contain any macroscopic population the writer has not seen any evidence therefor. If the conditions of a rising sea level made possible the burial of these beaches there might be an abundant burial of shells and sea weeds, resulting in an interesting association of marine organisms of which not a single one had lived either on or in the materials of the beach.

Sandy shores on the coast of Great Britain between high and low water mark of the spring tides show a distinct zoning from the high part of the beach downward and a distinct stratification in the distribution of the organisms, which from the top downward is as follows:

1. Floating and swimming forms present when the tide is in.
2. Surface dwelling species.
3. Stratum of *Cardium edule*, 1 to 2 inches beneath the surface.
4. Stratum of *Macoma balthica* and *Tellina*, 2 to 3 inches beneath the surface.
5. Stratum of the lugworm, *Arenicola marina*.[8]

The forms of life on the sandy shores as well as on shores composed of other sediments vary considerably due to the conditions of climate, salinity of waters, and other factors, but the factor of greatest importance for the burrowing forms seems to be the quantity of mud in the sands.

As many shore dwellers are burrowers and as the materials of shores

[8] Walton, C. L., *Lancashire Sea Fisheries Lab.* no. 28, 1920.

have little competency against collapse, it results that shells must be constructed to meet the pressures and other conditions to which they are subjected. Shells dwelling near the surface have more or less globular form, as may be seen in *Venus*, *Isocardia*, and *Cardium*, of which each valve of the bivalve shell is a strong dome. Shells living at greater depths in the sands, where the burden may be less because of greater compacting and where there is less possibility of shifting by waves, have flatter shells. This form of shell, exhibited by *Mya* and *Tellina*, permits easy passage through sands. Deeper dwelling requires lengthening of the siphons, which in turn compels modification of the shells to cover the siphons, and thus develops such shells as *Solen*, said to be able to burrow through sands at a surprising rate.

The population of some shore sands is extremely great. Herdman[9] states that there may be as many as 30,000 individuals of *Sabellaria*, an annelid, per square yard, and that the number of lugworms between tide marks on a beach a mile long may be between three and four million.

Some beaches are inhabited by numerous algae, but as a rule such plants are not common on sand beaches. Land plants, as *Salsola kali*, *Arenaria peploides*, *Cakile maritima*, and others, frequently live over the upper parts of beaches, but these have little likelihood of preservation.

[9] Herdman, W. A., *Linn. Soc., Jour. Zool.*, vol. 34, 1920.

The great number of burrowers in the materials of some sandy beaches results in many passages of the materials of the beach through the intestinal tracts of these animals, and if deposition is slow the materials probably pass through the intestinal tracts of succeeding generations. This will finally lead to disappearance of much or all of the organic matter. Small fragments may escape and be identified in the sands with the aid of the microscope. Experience demonstrates that many sands apparently barren of shell matter show it in finely divided form.

Circulation of water in shore sands is concomitant with waves on the shore, and it is rare that solution does not have opportunity in permeable sands to remove all soluble matter.

### THE ENVIRONMENT OF A SAND AREA BENEATH A LAKE OR SEA

*Sand bottom of a lake.*—A sand bottom in a lake is almost certainly in water of slight depth, perhaps 40 to 50 feet as a maximum in large lakes, except under very exceptional conditions, and at much less depth in small lakes. In lakes the population of invertebrates with hard parts, the only invertebrates of much significance for the stratigrapher, paleontologist and sedimentationist, includes few species, and at many places few individuals. Deposition of sands on most lake bottoms is likely to be slow and wave activity in small lakes is rarely great enough to wash the bottom sands at a depth of only a few feet, with the result that they

contain more or less mud. There are few burrowers with shells, usually none, and these forms, so abundant in marine waters, leave little record in lake sediments.

Planktonic and nektonic remains fall on sand bottoms after death as abundantly as on other bottoms, but, except for diatoms and fish, these do not add a great deal to the material entombed. Lakes without turnover are likely to have the deep bottom low in oxygen, thus favoring the preservation of organic matter, but at the same time restricting the volume of life. This turnover probably would have little effect on a sand bottom, as the depth is small and the presence of sand implies that waves and currents reach the bottom and supply oxygen. Solution is not favored while the sands are beneath the lake because of limited circulation, but if the sands contain much decaying organic matter all soluble matter may go.

*Sand bottom of the sea.*—Among the many and varied factors that affect aquatic organisms in the sea (and also in lakes) there seems to be none of such great importance as the nature of the bottom materials.[10]

Sand bottoms of the sea may have an abundant or a very sparse population. Bottoms of drifting sand are extremely unfavorable for supporting much of a population and there may be none. It was pointed out by Godwin-Austin[11] many years ago that a zone of drift-sand exists in the shallow waters of many coasts, and this sand contains little in the way of living shells. Most of the organic matter dredged therefrom has been derived from other bottoms. These sands, however, should contain considerable finely divided shell matter.

Sand bottoms ordinarily have few coelenterates, and pelecypods are dominant over gastropods. Burrowing forms are common. There may be Echinodermata, particularly starfishes, sea urchins and sand dollars. The population may be as abundant on some sand bottoms as those composed of other materials, but the kinds of individuals are very likely to be different. Work by Sumner[12] in Buzzards Bay and Vineyard Sound, two contiguous bodies of water on the New England coast, the former with much mud on the bottom and the latter with sand bottom, particularly over the western half, show decided differences in the bottom population. Many species dwelling on the sand bottom of Vineyard Sound are wanting on the mud bottom of Buzzards Bay and vice versa. Sumner's charts very clearly bring out the close relations between the organisms and the character of the bottom, and show that closely contiguous areas have different faunas. The benthonic fauna of Buzzards Bay after burial would represent a

[10] Sumner, F. G., An intensive study of the fauna and flora of a restricted area of the sea bottom: *Bur. Fish., Bull.*, vol. 28, pt. 2, pp. 1225–1264, 1928; Herdman, W. A., The marine zoology of the Irish Sea, *Brit. Assoc. Adv. Sci., Rept.*, pp. 318–334, 1894; Allen. E. J., On the fauna and bottom-deposits near the thirty-fathom line from the Eddystone Grounds to Start Point, *Marine Biol. Assoc., Jour.*, vol. 5, pp. 365–542, 1897–1899.

[11] Godwin-Austin, R.A.C., *Natural History of the European Seas*, p. 233.

[12] Sumner, F. B., *Op. cit.*

biocoenose, as the muds prove the waters to have too low competency to bring large shells to the Bay. Likewise the bottom faunas of Vineyard Sound would not be likely to have dead shells brought from Buzzards Bay for lack of competency in the waters of the Bay to take the shells away. Allen's studies of the fauna of an area near Plymouth, on the south coast of England,[13] show 230 species of invertebrates dwelling on sand bottoms and 24 species of fishes, of which most seem to be confined to water over sand bottoms. Evidently the fishes are either bottom ranging forms preferring a sand bottom, or they feed upon the animals and plants living on such bottom.

As the materials of the sand bottom are not very stable and the presence of the sands indicates that waves and currents affect the bottom, the animals living there must either be adapted to burrow in the sands, be provided with structures for anchorage, or be so shaped as to present little resistance to currents. Small forms may be numerous. Many shells burrow readily and do not have to go far from the surface to have adequate protection. Large pelecypod shells that do shallow burrowing have domal shapes but those that burrow to considerable depths are thin and flat. Some shells possess spines, wing-like processes, or other extensions to serve for anchorage. Starfishes have shapes that permit them to lie flat on the sands and thus present little resistance to the currents that more or less constantly move over sand areas. Starfishes also may sink themselves into sands and thus be removed from action of currents. Sea urchins tend to live in rather close colonies and swallow large quantities of sand for contained organic matter. Many gastropods, as *Natica catena*, *Buccinium undatum*, and *Nassa reticularis*, burrow readily. There are commonly many annelids and these may burrow to a foot or more. If deposition is sufficiently slow everything on the bottom that is possible of being swallowed passes several times through the intestinal tracts of annelids and other animals, and nearly everything organic may disappear or be reduced to small fragments. There result sands, such as one frequently finds in the Upper Cambrian of the upper Mississippi Valley, which have lost all semblance of stratification, and are macroscopically unfossiliferous. However, microscopic studies show that these apparently unfossiliferous sands may contain much shell matter in the form of minute fragments. The numerous burrows are eloquent as to the causes for the disappearance of shell matter and also the disappearance of laminations. Solution under conditions of slow deposition may account for the disappearance of much shell matter.

If deposition is rapid, organisms may be buried in large numbers. These may be excellently preserved, since burrowing animals can affect them little. Illustrations of this feature are thought to exist in the excellent preservation and abundance

[13] Allen, E. J., *Op. cit.*, *Marine Biol. Assoc.*, *Jour.*, vol. 5.

of mollusks in some parts of the Lower Cretaceous Mentor Beds of Central Kansas, and perhaps in the Glenerie (Oriskany) sandstones of eastern New York.

Sand areas on sea bottoms, as elsewhere, are there because the waters were incompetent to carry the sands away, but were competent to carry fine materials. The currents that brought the sands may also bring shell matter of dimensions comparable to the sands, thus introducing into the environment organic material produced on other bottoms. Likewise nekton from time to time may drop upon sand bottoms and plankton in the form of Radiolaria, diatoms, and Foraminifera may make considerable contributions. Thus a marine sand deposit does not always contain a fauna that was indigenous to the environment indicated by the sands.

Marine sands, in general, are upon relatively shallow bottoms, but there are places where strong currents reach to great depths and thus sand deposits reach corresponding depths. Illustrations are in Florida Strait, channels between the Canary Islands, and channels between the islands of the Mingan group on the coast of Quebec. As shown by Trask, sands tend to occur, among other places, on topographic highs of the sea bottom.[14] They may lie adjacent to the shore, or be separated from the shore by deposits of mud. Though, in general, they hold positions adjacent to the land areas, they have a rather sporadic distribution over the bottoms bordering the lands. The distribution is a function of the competency of the aquatic agents of transportation and the supply of materials.

A factor of much importance to the faunas of bottoms and shores of shallow epicontinental seas is the possibility of change in salinity of the water. This, of course, would affect faunas on all varieties of bottom. Such change in salinity may be caused on the shore and in the very shallow waters by rainfall or evaporation, and in estuaries by the tidal ebb and flow. The effect of brief changes in salinity is immediate on the animals in the water and those exposed on the bottom, but is not immediate on burrowers. Studies have shown that water permeating the bottom materials is not greatly modified, providing the change in the salinity of the overlying water does not endure too long. It is considered probable that in the shallow and restricted epicontinental seas of the Paleozoic and other eras there may have been seasonal changes of salinity connected with wet and dry seasons. During rainy seasons the inflow of stream water may have been adequate to render the waters brackish or fresh, whereas during dry seasons the inflow of stream water may not have been sufficient to care for the evaporation so that salt waters flowed in from the open sea. There also may have been longer cycles of wet and dry periods, and there may have been times of differ-

[14] Trask, P. D., Sedimentation in the Channel Islands region: *Econ. Geol.*, vol. 26, pp. 24–43, 1931. See also Shephard, F. P., *Science*, vol. 78, pp. 406–408, 1933.

ent salinity related to irregular constrictions or enlargements of the connections of the epicontinental sea with the open ocean. The hypothesis that constriction of connections of the epicontinental seas with the open sea may have led to the deposition of the evaporites has frequently been maintained, but little thought seems to have been given to the opposite possibility that constriction of such connection in a humid region might very readily have made the waters fresh, or that modification of the connection from time to time might have brought about alternations of fresh and salt water. It is considered as extremely probable that fresh and brackish waters frequently obtained in the shallow epicontinental seas and that these conditions occurred more often than excessive saltiness of waters. Such alternations would have had vast and profound influence upon the organisms dwelling in such waters, producing wholesale destruction of all benthonic organisms with each change of water and equally vast destruction of the nektonic and planktonic animals and plants. In view of the extreme shallowness of some of the epicontinental seas, as shown by mud cracks in many formations, as in the Ordovician of the Mingan Islands and the Appalachian Valley, the Upper Cambrian of the upper Mississippi Valley, and in other parts of the geologic column, such change of connections with the open sea would not have been difficult to make, nor would a large quantity of fresh water have been required to replace the salt water. Enlarging or deepening the connection with the open sea would have permitted return of salt water and return of marine organisms. It seems likely that such changes in salinity may account for the absence of marine organisms in strata of some of the geologic formations, as illustrated by barren sandstones in parts of the Upper Cambrian of the upper Mississippi Valley.

The tendency has been to consider a stratigraphic unit as entirely marine if any part of the unit contained marine fossils and if the unit were a part of a sequence in which marine fossils were present at several horizons. The position is here taken that only those strata should be considered marine that contain the marine fossils, and that decision respecting the environment of deposition of the unfossiliferous strata should be reserved, with the possibility held in mind that some of these strata might have been deposited in epicontinental basins containing fresh water.

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# PALEOZOIC FORAMINIFERA, THEIR RELATIONSHIPS TO MODERN FAUNAS AND TO THEIR ENVIRONMENT[1]

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ABSTRACT

Supposed Cambrian Foraminifera are all doubtful, except so-called *Spirillina* in the Upper Cambrian of England, which suggests by its form that the earliest types had tubular chitinous tests. From rocks between the Cambrian and the Carboniferous numerous Foraminifera of simple arenaceous types are known, but no definitely calcareous forms have been recognized. At present in lime-rich environments arenaceous forms with chitinous test in young stages become calcareous in later stages. It is suggested that this sort of process led to the later calcareous types. In the Pennsylvanian and Permian more modern types appear. Much work is still needed on the Paleozoic Foraminifera.

The Foraminifera, except for the family Fusulinidae, have not been considered until recent years of particular importance in the Paleozoic. New methods of treating material and more collecting have now revealed a rather large fauna extending through most of the Paleozoic. The light that these forms shed upon ecologic conditions of the times in which they lived must be described largely by comparison with later related forms, with living representatives where they exist, or with Cenozoic or Mesozoic forms. For many of the families of the present day fauna there can be little direct comparison, as they have appeared since the Paleozoic. However, research in recent years has given us a rather clear picture of what groups of Foraminifera existed in early Paleozoic time.

The earliest Foraminifera, like other Protozoa, were probably without definite tests. Such forms still live, and would, of course, leave no trace as fossils. The development of the group indicates undoubtedly that the earliest test was chitinous. Such tests also would leave little trace in the rocks, especially in early Paleozoic rocks that have been subjected to great changes. The next stage in the development of the Foraminifera was the attachment to the chitinous test of various foreign particles, thereby giving strength to the test. This type is seen throughout the fossil series and occurs in numerous families at the present time. Although the material of the immediate environment is used, there is, nevertheless, a rather definite selection of material by the animal itself, with the result that in an environment

[1] This paper was contributed to a symposium on paleoecology held at the meeting of the Paleontological Society in December, 1933. Manuscript received December 14, 1933.

which provides various foreign particles individual species may choose exclusively sand grains, or sponge spicules, or other material.

Through the kind help of Dr. B. F. Howell it has been possible to investigate at first hand a considerable number of so-called Foraminifera from the Cambrian or pre-Cambrian rocks of various parts of the world. Few of these show enough structure even to warrant their being placed with the Foraminifera. They consist for the most part of tiny nodular masses without structure or any definite arrangement. In most cases the test, if there ever was one, is lost, and the small body represents simply a cast that affords no definite knowledge of its original condition. Practically all of them may be discarded as having any relationship to the Foraminifera.

An organism in the Upper Cambrian of England, called *Spirillina* by Chapman, forms minute, coiled, tubular bodies without clear division into chambers. It is difficult to determine definitely what may have been the original material forming the test. The bodies are found in limestone and are now apparently preserved as calcite, though they are yellowish-brown, while the matrix of the material is a gray-white. Whether they were chitinous or calcareous in the original form cannot be determined definitely, for chitinous tests in other groups may be replaced by calcareous material. At least the shape of the test is definite and similar to the forms known in the arenaceous group as *Ammodiscus*, in the imperforate calcareous group as *Cornuspira*, and in the perforate calcareous group as *Spirillina*. The discovery of these Upper Cambrian forms, therefore, seems to indicate very clearly that the earliest forms of the Foraminifera were, as has been widely held, tubular, and consisted of an early proloculum and later elongate undivided chamber that is most often coiled about itself in a single plane. A slide of the original material has been received through the kindness of Doctor Chapman and is being studied in detail to determine its true character.

Of the Foraminifera of the rocks between the Cambrian and the Carboniferous there has been until recent years very little known. I have examined many hundreds of thin sections of these rocks without finding anything that may be definitely called Foraminifera. A recent letter from Doctor Chapman speaks of a similar experience with the Devonian. He says, "It is strange that so little has been discovered in the Devonian. I have cut hundreds of sections of limestones from various localities, but without result." Recently, Moreman, Croneis, Dunn, and others, by the method of dissolving pre-Carboniferous limestones slowly, have discovered rather rich faunas widely distributed in these rocks. All of these Foraminifera belong to a rather simple arenaceous type and still further show that the early Paleozoic species were arenaceous, simple in structure, the test consisting of a chitinous inner layer and outer arenaceous one very similar

to tests found throughout the fossil series. No definitely calcareous forms have been recognized through this long stretch of time. On the other hand, the forms that do appear belong to the groups long considered as the most primitive of the Foraminifera, and are the exact types that from studies of later forms would be predicted to occur in the early Paleozoic. In the present oceans such forms occur widely distributed in various habitats, perhaps most commonly in waters of medium depth in temperate regions. Although arenaceous forms are also found in brackish and in deep water environments at present, this is due to their ability to persist in such habitats (whereas the forms with calcareous test cannot) rather than to any preference for such conditions. Arenaceous faunas are usually most abundant and most varied in species and genera in relatively shallow water. The cementing material used to fasten the foreign material to the outside of the chitinous test may be itself chitinous or of other composition. In waters where calcareous materials are available the cement gradually becomes calcareous even though the earliest part of the test may be chitinous. In such forms the whole test may be broken down in acid but a residue of foreign material is present. It has been found by careful experimentation that very weak acid acting over a long period dissolves the calcareous cementing material without disrupting the structure of the test itself. The arenaceous material may be kept in place and the structure of the entire wall easily seen. I have been able in this way to study type material of *Bradyina* from Russia. The entire shape and structure is beautifully preserved, though all the calcareous cementing material has been dissolved away, leaving the fragments of which the test is largely composed. The change from an arenaceous to a calcareous habit may be seen in such genera as *Eggerella* and *Cymbalopora*. There seems to be no retracing of this development, although it has been claimed sometimes that calcareous forms develop arenaceous exteriors. It is true that in some parts of the Red Sea, for example, where excessive evaporation makes the lime content of the water very high, calcareous Foraminifera are found with the sand of the bottom cemented to the exterior. This same condition, however, occurs in all the molluscan shells, worm tubes, and other hard parts of animals living under these conditions. Such features can be due only to the peculiar environmental conditions and not to an evolutionary development of test characters.

In the Pennsylvanian and Permian, new types more like the modern ones appear. Calcareous imperforate forms such as *Cornuspira* and many related genera occur in considerable numbers, becoming a more important part of the fauna in the Permian. Many of these forms are attached, as are also those of the arenaceous group. A considerable number of them become specialized and are limited to the Paleozoic.

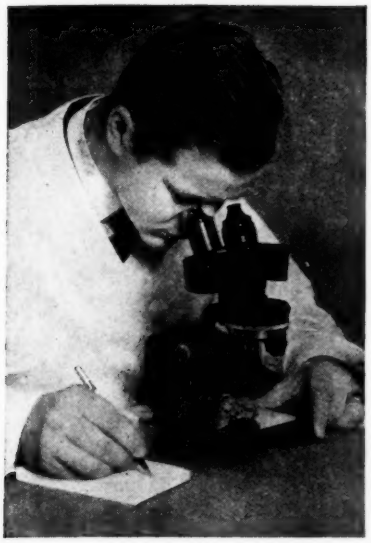
In general the Paleozoic Foraminifera are primitive forms, predom-

inantly arenaceous, and include relatives or actual representatives of numerous families and many genera known today in the present oceans. The great group of the Fusulinidae are derived also from arenaceous forms and show, at high magnification, the fragments of which they are composed. The cementing material here, however, often becomes predominant, as it does in such genera as *Glomospira* and *Glyphostomella*. The Fusulinidae form a very specialized group and need a particular technique in their study. I, therefore, do not feel competent to discuss them in detail. It may be noted that later in the post-Paleozoic series, *Loftusia* appears, very similar to the fusulinids in many characters, truly arenaceous, and reaching a far greater size than any of the Fusulinidae.

The Paleozoic Foraminifera need much more close study than has ever been given them. The method of using very weak acid on the tests will undoubtedly continue to give a great deal of information. The study of thin sections with polarized light and ultra violet light also will probably give a large amount of information as to the exact characters of the tests in many forms. The methods of staining worked out by Henbest and others has already proved its great usefulness. All these methods of research will aid in clarifying the relationships of primitive forms to those of the post-Paleozoic.

A word of caution as to accepting material which one has not himself prepared might be noted here. I have had material sent me as Paleozoic from Oklahoma containing very beautiful *Globigerina* of known Upper Cretaceous species. When attention was called to this, check washings of the same material showed nothing of this sort, and it was found that Cretaceous samples had been washed a short time earlier, and probably the sieves were not carefully cleaned. Not long ago I had material sent me which was labelled "Carboniferous of Cornwall, England." On examination this proved to contain several species of Pliocene age and to have come from St. Erth in Cornwall. The error was due to carelessness in labelling by someone not familiar with the material. Such accidents might easily result in the publication of records which would be about as far from scientific truth as could well be. Undoubtedly some of the records now given for the Paleozoic are based on specimens which did not come from Paleozoic rocks but crept into the samples through some error.

The Paleozoic Foraminifera will well reward the careful student endowed with patience to undertake investigations through these newer methods that have been suggested, and when they are fully studied will probably be of very considerable help in showing the conditions under which they lived in the Paleozoic.



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## Binocular Microscope

**MODEL "BI-K"**
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***Write for Bulletin No. 9 (625)***

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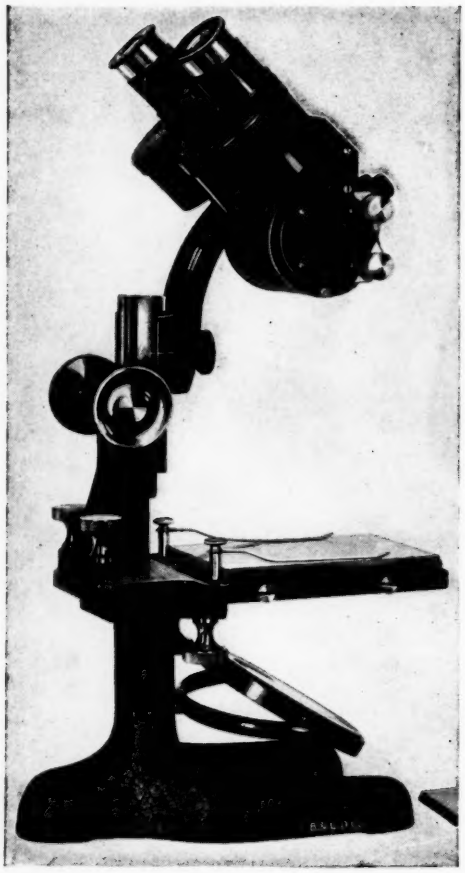

Illustrated above is the BKT Model with extra base and inclined eyepiece. Other models are available for various purposes.

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2. The field of view covers a larger area of specimen than other instruments of comparable power.
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4. All eyepieces are flat on top, preventing reflection and glare.
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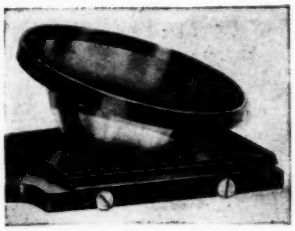
6. Special accessories and lamp give the best performance.



At the right is a tilting specimen holder, a convenient accessory for use with the KW Microscope.

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